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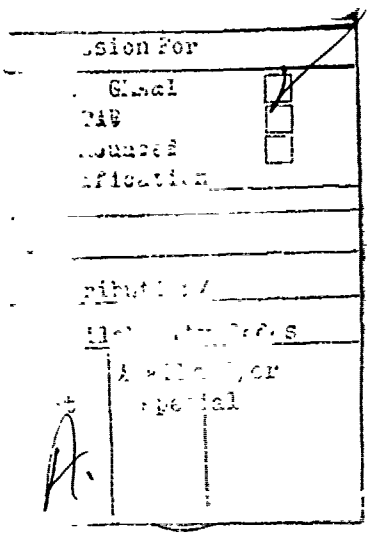

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This is the third volume of a series dealing with human performance in continuous operations. This volume documents the technical procedures used to analyze adverse effects and to project diminished human performance capabilities during continuous operations, as described in Volumes I and II of this series. Specifically, the present volume (Volume III of the set): (1) depicts the technical aspects of the development of the prior two volumes, (2) updates a prior survey of the literature concerning the effects of continuous operations on military performance, (3) describes the methods for deriving "critical"

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tasks included in Volume I, (4) describes the details of the mathematical procedures employed in Volume I to calculate and compound projected performance effectiveness, and (5) describes the details of a computer simulation model, which incorporates human effects, for simulating human performance in continuous operations.

Research Product 80-4c

Human Performance in Continuous Operations: Volume III Technical Documentation

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FOREWORD

Night and continuous operations place new and unique demands on operating personnel. Effective doctrine and tactics cannot be formulated unless human capabilities and limitations in this environment are understood and accommodated through equipment aids, new operating procedures, and special training, as well as revised manning and rotation cycles.

The most recent product of ARI research on Human Performance in Continuous Operations consists of three volumes. This document, Volume III, Technical Supplement, depicts the technical aspects of the development and background data for the information contained in Volumes I and II, and describes the methods for predicting performance degredation. Volume I presents Guidelines to the military user on expected human performance capabilities during continuous combat. Volume II provides a Management Guide on how to minimize expected performance decrements during continuous operations. Together they update and replace ARI Research Product 79-8, "Human Performance in Continuous Operations Guidelines", and Technical Report 386, which provided background data. The three volumes provide a body of general and highly specific information about the soldier's tasks on which degraded performance can be anticipated during continuous operations. Such information will be useful to tactical planners, training specialists, and design engineers.

The research was conducted under Contract DAHC 19-77-C-0054, as part of Army Project 20163743A774, Man-Machine Interface in Integrated Battlefield Control Systems, FY 1978 Work Program. The research was supported by CACDA/CATRADA at Fort Leavenworth, Kansas, which was the TRADOC sponsor. Special thanks are due to Colonel Robert N. Morrison, Major Michael G. Jones, and Major Robert O. Livingston for their recommendations and cooperation.

JOSEPH ZEIDNER
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PREFACE

This volume is the third of a series dealing with human performance in continuous operations. The present volume supplements two companion volumes Guidelines - Human Performance in Continuous Operations and Human Resources Management Guide, and documents the technical procedures used tc analyze adverse effects and to project diminished human performance capabilities during continuous operations. Volume I of the set, the Guidelines, presents the known effects of variables associated with continuous operations on the performance of the critical military tasks of:

- mechanized infantry personnel
- FIST personnel
- tank crews
- artillery battery personnel

It presents and projects probable performance effectiveness at the squad, platoon, and company level and indicates the effects of task restructuring on such effectiveness.

Volume II of the series describes a set of management actions that can be taken prior to the continuous operations so that performance will be maximal and so that performance effectiveness will be sustained. It delineates the human resources management issues in anticipation of and during continuous operations. It also outlines the management actions designed to maximize human resources and to conserve them thereafter.

The present volume (Volume III of the set):

- depicts the technical aspects of the development of the companion volumes
- updates a prior survey of the literature concerning the effects of continuous operations on military performance
- describes the methods for deriving "critical" tasks included in Volume I
- describes the details of the mathematical procedures employed in Volume I to calculate and compound projected performance effectiveness
- describes the details of a computer simulation model, which incorporates human effects, for simulating human performance in continuous operations

Accordingly, the present volume provides the technical backdrop for Volumes I and II. Each volume is written so as to stand alone. However, in some cases, reference is made to earlier volumes. This procedure avoids unnecessary duplication and is not believed to detract from expositional clarity or continuity.

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CHAPTER I

FIELD STUDIES PERTAINING TO HUMAN PERFORMANCE IN CONTINUOUS OPERATIONS

The need for the present work stems from: (1) the current political climate, (2) recent Soviet military activity, and, most fundamentally, (3) evolving military tactical doctrine.

A number of current Army field manuals contain information about fighting and/or conducting operations at night. Whole manuals have been devoted to fighting at night. Some of these were written years ago. The early conception of night operations, however, was quite distinct from continuous operations as they are presently understood. As an example, an early manual titled Night Operations for Infantry (Dawkins, 1914) conceives of night operations as an occasional surprise attack, movement of troops to a position for an attack at dawn, or operations of sabotage or reconnaisance. More recent thinking is found in such documents as the U.S. Army Command and General Staff College Special Bibliography on Night Operations (1976), the Army Research Institute research memorandum on night operations (Weitzman, 1977), and the U.S. Army Combined Arms Center Concept Paper on Night Operations (1975).

The major impediment to night operations has been darkness. Most of man's visual information accessing ability is limited to information contained in the medium of reflected light. The development of sophisticated devices which serve as substitutes for or enhancers of man's visual information accessing ability have dramatically increased the capacity for night operations. These include such devices as: field radar, night vision scopes and goggles, and thermal imagery devices.

Once the major impediments to night operations, i.e., the ability to access necessary information, was removed, a new dimension was added to combat tactics. The possibility of conducting operations at night signaled the potential for uninterrupted battle. However, uninterrupted battle is a concept associated with its own set of problems. If a battle can be waged at night, it can be waged continuously. But constraints on equipment and men limit the length of a battle.

The Soviets (Betit, 1975) have given serious thought to these constraints and claim to have made strides to compensate for them (Emanski, 1977). The human problems associated with continuous operations were directly addressed earlier by various groups at a conference held at Texas Technical University (Hodge, 1972) and by other University based scientists (Morgan, et al., 1977).

One result of the interest in continuous operations has been the need to learn the implications of such operations for the soldier. If one sets the battle performed by fresh, seasoned troops under ideal, daylight conditions as the standard, one can measure the implications of continuous operations as deviations from that standard. Not surprisingly, nearly all of the deviations from the standard seem to be related to limitations on human performance, particularly sleep loss (Opstad, Ekanger, Nummestad, & Rabbe, 1978).

There is then a need to locate and assess the accumulated scientific literature for information bearing upon these issues. The assessment required a good deal of judgment, because the applicability of laboratory studies to military reality cannot be taken for granted. Chapanis (1967) summarized the faults found in studies as they deal with attempts to apply laboratory results to real-life situations: (a) only a few independent variables are selected so that many important interactions may be excluded, (b) the character of the variables is often changed inside the laboratory, (c) experimental conditions are so well controlled that significant differences found in the laboratory are later found to be of no practical importance in the field, (d) the methods used to present variables are unrealistic, and (e) criteria are chosen for convenience rather than relevance. He concluded that "one should generalize with extreme caution from the results of laboratory experiments to the solution of practical problems."

The literature summarized in the next section is based on military field surveys and observations rather than on laboratory studies. It constitutes an extension and continuation of a prior literature survey (Pfeiffer, Siegel, Taylor, and Shuler, 1979).

Field Studies of Continuous Infantry Operations

Recently, a British army research organization completed a field study of the effect of continuous operations on the performance of the infantryman (Haslam, et al., 1977). The study was based on a nine day tactical defensive exercise to compare the performance of three platoons of infantry scheduled respectively for 0 hours, 1.5 hours, and 3.0 hours sleep every 24 hours. While the exercise was carried out in England during the summer, the weather was, for the most part, cold, wet, and windy. On the fourth day, a heavy rain fell. Even small amounts of sleep proved beneficial. Experienced military observers judged that the physical tasks were carried out at an acceptable level by the platoon with 0 hours of sleep over three days, by the platoon with 1.5 hours of sleep over six days, and by the platoon with 3.0 hours of sleep over nine days. On the other hand, performance of most cognitive and vigilance tasks deteriorated from the very first day of sleep loss.

Physical Performance

In the British study, well learned and mainly physical tasks did not deteriorate with sleep loss. While acutely sleep deprived soldiers were able to maintain their speed of march across country, the platoon leader experienced map reading difficulty. Fine psychomotor performance, such as stripping and assembling a rifle, showed high variability. The easier task of filling the magazine was not adversely affected while aspects requiring more precision were adversely affected. Apparently, well learned, routine, noncomplex tasks were extremely resistant to sleep loss.

Leadership

The British study found that tired soldiers, rather than becoming aggressive, became docile. Morale and camaraderie remained high throughout the period. Platoon and squad leaders reported they had more success with their men when a relaxed style of leadership was adopted.

Cognitive Performance

Cognitive tasks most severely affected by sleep loss were those which involved encoding/decoding, logical reasoning, accurate perception, and concentration. Mental tasks least affected were those involving short term memory. It was thought that a proper level of morale and motivation can counteract the degradation of cognitive tasks due to sleep loss.

Field Studies of Sustained High Rates of Artillery Fire

Recently a survey was completed for the U.S. Commander, V Corps Artillery, by Manning (1978). Manning collected information which bears on the following three questions:

- Can artillery crew members withstand physical stresses involved with handling large quantities of ammunition and firing at a high rate over a prolonged period?
- What is the psychological impact of firing at a high rate for prolonged periods?
- What leadership traits may be indicated as essential in accomplishing such a mission?

On the basis of observations, interviews, and literature reviews, Manning estimated that 36 hours of continuous performance is a reasonable guess at the endurance of a typical corps level cannon battalion under conditions of high intensity combat. He pointed out, however, that serious and potentially

fatal deficiencies are likely after only 24 hours. Manning pointed out that several potentially controllable factors exist which might extend reliable performance to 60 or even 72 hours:

- Sleep for leaders is by far the most critical of these, due to the high sensitivity of decision making and other cognitive tasks to fatigue. At present, this fact is simply unacceptable to the vast majority of leaders at battalion and lower levels, at least with regard to themselves.
- Cross-training is essential at all levels, command included, if any kind of shift work is going to be possible (and significant reinforcements from CONUS will certainly not arrive fast enough to avoid shift work), or if the unit is going to survive the inevitable losses of key personnel.
- Unit cohesion, the extent to which the men of the unit see themselves as a unit or team in which teammates can't let a buddy down, was a crucial determinant of endurance in World War II. It should still hold true.
- Worries about dependents' care will play a large role in staying power, if we may generalize from the Israelis' "combat reaction" casualities of 1973. As a working hypothesis relating sleep of leaders, unit cohesion, and concern about dependents, to continuous operations, it is likely that endurance is an inverse function of the number of competing loyalties experienced by an individual in time of stress.
- Nuclear and chemical warfare will not only directly influence survival, but by engendering feelings of helplessness and hindering communication, it will also have a significiant role on soldiers' will to continue.

Field Studies of Fire Direction Center Teams

Manning (1978) also reported quasi-experimental observations of Fire Direction Center (FDC) teams from the U.S. 82nd Airborne Division. These volunteers were all five man teams who operated without the assistance of FADAC. All teams carried out an artillery combat scenario in support of light infantry. Factors simulated included dynamic communication over radio and telephone nets, appropriate sound effects, realistic terrain problems,

and the physical arrangements of an operational environment approximating field conditions. Two teams were informed that they would be expected to perform continuously for 86 hours. One of these teams withdrew after 46 hours because of exhaustion and the other after 48 hours because it believed itself to be performing inadequately. Two other teams were required to perform for a shorter period in a combat scenario. These two latter teams performed for 38 hours continuously, rested for 34 hours, and then were required to perform for 38 hours more. Both of these teams completed their scenarios.

From extensive psychological and physical observations during the simulation and recovery periods, conclusions reached by Manning were:

- As time on task increased, there was evidence of increasing errors and slowing of output on some tasks. The practical implication of these findings in determining overall effectiveness requires more analysis.
- FDC members judged the teams' performance to be ineffective at a time substantially prior to any observations of actual combat ineffectiveness. Although overall team performance levels were at or above ARTEP standards, individual errors and some firing errors led the teams to evaluate their performance as deteriorating. Adverse self evaluation was a factor in declining morale.
- While performance on standard firing missions was maintained, times to deliver preplanned target information to the battery increased.
- Preplanning decreased as teams strove to meet immediate fire demands, or used lull periods to rest. Accompanying this was a failure to maintain appropriate target priority. Teams with less experience and longer times on task had the greatest problems in this regard.
- Observed performance difficulties were greatest during multiple fire missions. Firing times lengthened and some missions were unintentionally omitted.
- Despite the lack of physical exertion, teams reported increased physical fatigue. This was particularly marked during the early morning hours. Adverse self evaluation of performance also tended to occur at this time.

- Teams reported increased loudness of verbalization, confusion, and difficulty in communication after prolonged work periods. These problems seemed attributable to frequent lapses in attention, difficulty with short term memory, and increased difficulty in accomplishing more than one task at a time. These effects which increased after the missing of one night of sleep appeared to be secondary to sleep deprivation.
- After extended periods of performance, some team members reported difficulty in focusing their eyes. This was manifested as blurred vision and misidentification of targets on the chart. Other visual performance data were not collected in these preliminary studies.

Field Studies of Continuous Tank Operations

To simulate a combat situation, Ainsworth and Bishop (1971) designed a 12 hour tactical problem utilizing a specially constructed 35.7 mile long problem course for tanks. The problem included offensive, defensive, and retrograde movements. Performance tests were conducted at specified points along the course for basic tank crew activities: communication, driving, surveillance, gunnery, and maintenance.

An experimental group of 20 tank crews was required to complete the 12 hour course four consecutive times for a total of 48 hours of activity without sleep. A control group of 10 tank crews also repeated the course four times but were given a 24 hour rest period between each 12 hour work period. Both time and performance accuracy scores were obtained in most of the performance tests. The effects of the continuous activity were determined by comparing the trends of the scores for the two groups during the course of the experiment, as well as by comparing their performance scores.

In comparison with the control group, the experimental group exhibited little performance decrement in the communication, gunnery, and maintenance exercises and in two of the driving exercises. The performance of the experimental group was significantly worse than that of the control group only in moving surveillance and in two of the driving exercises. Differences between the groups in the performance of these as well as the other exercises were small, however. Only minor and usually insignificant differences were found between the scores obtained during the day and those obtained during the night periods.

The major conclusions of Ainsworth and Bishop were:

- Activities that demand a protracted high level of alertness or require complex perceptual-motor activity, such as the moving surveillance and some driving tasks, are the most sensitive to the adverse effects of loss of sleep.

- Under field conditions, tank crews are able to perform present day communication, driving, surveillance, gunnery, and maintenance tasks without serious performance decrements during a 48 hour period without sleep.
- Under field conditions, performance at night is not significantly affected by the diurnal rhythms of the subjects (but may be affected by reduced visibility).
- The results of this investigation do not indicate that changes in unit organization or tactical doctrine are necessary to accomplish continuous tank operations for periods up to 48 hours.

Summary of Effects of Sleep Loss

Woodward and Nelson (1974) provided a comprehensive, military oriented review of the literature on the effects of sleep loss, work-rest schedules, and recovery on performance. Most of their summary statements on the effects of sleep loss and recovery are provided below. Each statement is a paraphrase of a finding in an original, documented study:

- The effect of sleep loss on performance varies widely from essentially no effect to an almost complete breakdown in performance.
- Within broad limits, the crucial variable in predicting whether sleep loss will have an effect on performance is the factor of interest. Interesting tasks involving relatively simple motor skills appear resistant to the effects of sleep loss for periods of as much as 60 hours.
- Performance on routine, monotonous tasks tends to show rapid and severe decrement after periods of more than 24 hours without sleep.
- Increasing task complexity or task difficulty, without a concurrent increase in interest, will result in greater performance decrement after sleep loss.
- Newly learned skills, or skills that are not well practiced, are more affected by sleep loss than skills that have become automatic or "second nature."

- Sleep loss of 24 hours or more impairs the acquisition and immediate recall of newly learned material (facts of discrete nature), but has little effect on recall of such material previously learned.
- After a sleep loss of 24 hours or more, it takes more time to learn relatively simple concepts. There is no significant impairment in quality of concept attainment. Both speed of learning and quality of concept attainment would probably be affected if a long chain of reasoning and memory of complex decision chains were involved.
- As sleep loss progresses, brief intermittent lapses in perceptual performance increase in both frequency and duration.
- Performance on self paced tasks generally shows little loss in accuracy, but responses tend to be slower after sleep loss.
- High workload situations are more affected by sleep loss than are low workload situations; in general, as the time available for making responses increases, the task becomes less sensitive to sleep loss effects.
- Chronic sleep loss will lead to performance impairment and mood change if the sleep loss is of sufficiently long duration and the total time period sufficiently prolonged (e.g., the chronic sleep loss represented by a reduction by 50 percent in one's normal number of hours asleep per 24 hour period for seven consecutive days or more).
- Sleep loss consistently produces impairment of vigilance performance; the major effect is an increase in missed signals or errors of omission.
- Communications tasks are differentially affected by sleep loss. Typically, the time required for sending information increases with sleep loss, as does the number of errors, although the errors generally are corrected. In receiving information, however, errors of omission (of missing part of the message) increase significantly with sleep loss.
- Tasks that involve varied physical activities are usually more resistant to performance decrement during continuous work periods of 36 to 48 hours without sleep than are relatively sedentary tasks primarily requiring mental activity.

- As sleep loss increases, performance becomes more uneven, with periodic lapses in efficiency being more characteristic than a continuous depression of performance.
- During a work period beginning between 0800-1200, major performance decrements first appear after approximately 18 hours of continuous work.
- Investigations of sleep loss effects have shown that the poorest performance frequently occurs between 0200-0600 hours, which corresponds to the low segment in the typical circadian rhythm.
- Typically, performance impairment during continuous work tends to increase as a function of the number of hours spent awake, but is subject to a superimposed variation from the influence of circadian rhythms.
- Average performance decrements as great as 40 percent below baseline levels can be expected toward the end of a 48 hour period of continuous work with no sleep, breaks, or catnaps.
- The wide individual differences in performance induced by sleep loss are not related to standard measures of personality or intelligence.
- Sleep loss has a negative effect on an individual's mood or disposition, as evidenced by subjective reports of increased hostility, irritability, depression, fatigue, etc.
- Breaks in a task appear to delay the occurrence of sleep induced lapses until later stages of the work period.
- The performance effects of sleep loss are usually accentuated as time on task increases and rest periods or breaks in routine are not permitted. Almost any interruption of the task helps to return performance to the initial level, but performance tends to decline quickly if the task is immediately returned to after the break.
- Lapses resulting from sleep loss are strongly affected by task monotony; the more monotonous tasks seem to be related to more frequent lapses.

- Sleep loss consistently produces an increase in average reaction time.
- In work situations with several tasks that are differentially weighted in importance, the operator will attempt to maintain his performance on the primary or most important task at the expense of poorer performance on less important or secondary tasks. This is especially true if the operator is at or near his performance load capability.
- The effects of acute sleep loss on performance will be noted sooner and will tend to be more severe than the effects of chronic sleep loss of equivalent duration.
- To minimize the performance impairment resulting from sleep loss, the task should be structured to permit periods of relaxation of performance and opportunities to recover from or compensate for the perceptual lapses that can be expected to occur.
- The 12 hour period preceding a prolonged work or sleep loss period should be kept as free of duties as possible and, ideally, should be spent in sleep to minimize performance decrements during the later sleep loss period.
- After 36 to 48 hours of continuous work without sleep, six hours of sleep (or less) is inadequate to return performance to normal levels.
- Recovery of performance from acute sleep loss of up to 48 hours generally is complete after 12 hours of sleep/rest, although subjective fatigue is reported until after the third full night of sleep.
- Sleep loss of 72 to 96 hours will require more than one recovery night of sleep before performance recovery is complete.
- If a period of 36 to 48 hours of continuous work is imposed on a normal load of eight hours per day, 12 hours of rest appears sufficient for performance recovery. If the same period is imposed on a work load of 12 to 16 hours a day, it may take as much as 24 hours of rest of performance to recover.

- After enduring a stressful period of sleep loss and having gone to sleep, men should not be awakened for duty until they have obtained adequate sleep, unless one is prepared to accept very low performance efficiency in their work.
- The performance of individuals just after being awakened from a normal night of sleep typically will be below normal for at least 15 minutes.
- The absolute amount of sleep, rather than a particular electroencephalographically defined stage of sleep, determines performance recovery.
- Task rotation among cross trained crewmembers will reduce performance deterioration, especially for relatively routine, boring tasks. Complex tasks involving decision making will benefit least from crew rotation unless the men are well practiced and expert in shifting functions.
- Stimulant drugs will alleviate some of the performance degrading effects of sleep loss.
- Mild physical activity, such as walking around, frequently will alleviate sleep loss effects temporarily.

CHAPTER II

TASK ANALYSIS AND WEIGHTING

The present chapter deals with task identification, task utility (importance) derivation, and aggregation of criticality values for the tasks included in the companion Guidelines.

Task Listing

In any analysis of human performance it is necessary to specify the activities involved in the performance as well as who performs each activity. An initial step is to develop an inventory of tasks performed by various duty positions and to list them. Such a list was derived from a scenario describing an active defense against a breakthrough attack by threat forces in a mid European region. The scenario and the task lists are contained in the companion Guidelines (Chapters I and II). The scenario also identifies the conditions under which the tasks are assumed to be performed in the present analysis:

(a) a representative mid European summer environment with day-night temperatures between 50° and 90° F

(b) conflict emphasizing combined arms team operations

(c) continuous day-night battle extending over a period of five days

(d) periods of rain and limited visibility

(e) initial adversary manpower superiority of six to one

(f) nuclear capability on both sides and a reluctance on both sides to use this capability

(g) own forces are faced with conduct of an active defense after reducing the manpower superiority to a manageable three to one ratio with conventional weapons.

Each task, derived on the basis of the task analysis, was included in a decision theoretic type of analysis to derive the most important tasks for the active defense. These most important tasks formed the basis for the companion Guidelines.

Method

Task List Assembly

Four types of units represented the concept of the combined arms team: mechanized infantry. FIST, tank crews, and a direct support artillery battery's gun crews. The task list assembly involved the following major steps:

- Selection of source materials. Source materials consulted during the preparation phase included: FM 7-7, TC 7-1, FM 71-1, FM 71-2, FM 6-40, FM 6-50, FM 6-13 B 1/2, ARTEP 6-105, ARTEP 6-165, TC 6-20-10, FM 17-12, TC 7-3-1, ARTEP 17-35, FM 100-5, The Military Occupational Data Bank, and a variety of military journals, particularly for FIST.
- Development of Preliminary Inventory. Initially, a large pool of task statements was organized into duty groupings. The analyst than consolidated the statements, eliminated duplications, and composed a single list of statements for each position within each unit type.
- Review of Inventory. The preliminary task list was then reviewed by the technical military advisor to the program. He added any tasks important to the scenario that had been omitted and indicated whether any listed tasks should be consolidated, broken down further, or eliminated. He also judged whether each task statement, as given, was clear in meaning or whether it should be reworded.
- Preparation of Final Inventory. The job analyst then reviewed the suggestions of the military technical advisor and derived four final task lists that took advantage of all suggestions. The four final lists distributed tasks across units as follows:

Mechanized Infantry	263 tasks
Armor (Tanks)	218 tasks
FIST	188 tasks
Artillery	137 tasks

For purposes of identifying the most critical tasks, each list was subjected to four multiattribute utility analyses. These four analyses involved: (1) an analysis relative to the utility of each task for achieving the overall active defense goals, and (2) an analysis relative to the utility of each task for achieving each of three sets of specific platoon action goals within the overall scenario. The results of the four analyses were combined to yield a final list of tasks for each of the four types of unit.

Multiattribute Utility Analyses

While the multiattribute utility analytic technique has been called MAUT (Edwards, Guttentag, & Snapper, 1975), the same analytic method was called the simple multiattribute rating technique (SMART) by Gardiner and Edwards (1975). Both SMART and MAUT transform what the decision maker knows into numerical values that are consistent and meaningful in the context of an additive utility model. Edward's technique, as employed here, is designed to provide a measure of the utility of each task for achieving goals. Two independent stages of measurement are involved. When the results of these two stages are combined, the criticality (utility) of each task is acquired.

Importance of Mission Goals

The first step in the task utility derivation, as applied here, involved: (1) deriving the utility of each task relative to the general mission goals, and (2) weighting the general mission goals in terms of their relative importance.

To identify general mission goals, a variety of Army field manuals was consulted. Review of these manuals produced seven goals. These are listed along with the importance weighting of each goal in Table 2.1. This weighting was accomplished by the program's technical consultant on military matters.

Table 2.1

Importance of General Mission Goals by Unit Type Engaged in an Active Defense

Goal	Unit Type			
	Mechanized Infantry	Armor (Tanks)	FIST	Artillery
Maintaining tactical and strategic objectives	.25	.10	.25	.11
Preserving forces, facilities, etc.	.21	.21	.21	.18
Controlling essential terrain	.18	.07	.14	.04
Maintaining ability to move forces	.14	.19	.04	.07
Wearing down enemy forces	.11	.26	.18	.25
Forcing the enemy to mass	.07	.05	.11	.21
Gaining time advantage	.04	.12	.07	.14
Σw_j =	1.00	1.00	1.00	1.00

To obtain the goal weights, the goals were first rank ordered by the program's technical military consultant. Then, the rank order of each goal was converted to a value on a scale which ranged from zero to one. Note that the weights for each goal shown in Table 2.1 sum to 1.00 for each type of unit.

The key to the successful application of utility theory lies in the proper scaling of the mission goals. Fortunately, the scaling was somewhat simplified in the present case, because only a conversion from an ordinal to a ratio scale was involved. The most important general mission goal (maintaining tactical and strategic objectives) was assigned a value of seven and the least important goal was assigned a value of one. After all dimensions had been ordered, the sum of the ordinal numbers assigned to all seven was obtained and each was divided by this sum. In this way, ordinal scale values were converted into proportions of total importance contributed by each of the seven mission goals. However, since the final decisions based on this MAUT analysis required nothing better than an ordinal scale, the conversion from an ordinal scale to a ratio scale was really a matter of convenience.

Weighting Tasks on Mission Goals

The second stage of Edwards' measurement technique involves determination of the contribution of each task to mission success. This measurement was accomplished for the general mission goals by the program's technical military consultant who estimated the contribution of each task to the accomplishment of each general mission goal. Table 2.2 provides the questionnaire instructions which were employed for the mechanized infantry. The questionnaire format and content were the same for each type of unit: mechanized infantry, armor (tanks), FIST, and artillery.

Table 2.2

Questionnaire Instructions for Identifying Task Importance

structions

Your task is to determine how important each of a set of tasks is to achieving each of a set of mission goals. Please remember that all of your judgments are military judgments. The goals presented are general mission goals involved in active defense and the tasks include those of the vehicle driver, carrier team leader, infantry maneuver team, squad leader, and platoon leader.

Scaling. Use any number between 1 and 99 to express the degree of task importance. A low number means low importance and a high number means high importance. Complete the scaling of importance for all tasks and positions at one sitting. Don't stop till you have finished the job.

Example. Here the task is assumed to be camouflaging. A list is presented below with a completed example.

Task Criticality	General Mission Goals
90	Preserving forces, facilities, etc.
50	Maintaining tactical and strategic objectives
80	Gaining time advantage
10	Maintaining ability to move forces
20	Wearing down enemy forces
5	Controlling essential terrain
5	Forcing the enemy to mass

Utility

Following Edwards et al, the calculation of the utility of each task for the general mission goals was calculated in accordance with:

$$U_i = \sum_{j=1}^{n=7} (w_j \; u_{ij}), \tag{2-1}$$

where $\sum_{j=1}^{n=7} = 1.00$,

U_i is the aggregate utility for the i^{th} task,

w_j is the normalized importance weight of the j^{th} mission goal, and

u_{ij} is the rescaled position of the i^{th} task on the j^{th} mission goal.

The results are presented in the second column (General Goals) of Tables 2.3, 2.4, 2.5, and 2.6.

Table 2.3

Utility Ratings for Mechanized Infantry Tasks

VEHICLE DRIVER (DR)	Critical Task No.	General Goals	Goals of Action 1	2	3
Receive orders and plans from PL		73	86	42	57
Review terrain maps with SL		64	68	43	59
Check fuel supplies		54	83	62	62
Check vehicle use supplies (water, recovery devices, etc.)		45	84	62	70
Check APC mechanical readiness		25	83	76	76
Load APC materials		23	35	66	68
Review SOPs and special orders with SL		09	44	62	56
Mount vehicle		18	71	61	66
Start engines		16	65	48	65
Drive under visual guidance, daytime		36	85	54	61
Drive under visual guidance, formation lights		23	84	44	62
Drive with NVDs		24	85	44	66
Drive in lead position		09	82	44	64
Drive under SL intercom control		07	80	44	63
Drive under PL hand signal control		09	–	39	73
Prepare to cross water		08	–	–	–
Cross water		23	–	–	–
Secure after crossing water		33	–	–	–
Drive over rough terrain		31	59	47	73
Position bounding vehicle		25	70	69	78
Position overwatching vehicle		39	72	67	78
Locate covered area		33	68	59	73
Position vehicle in covered area		33	61	65	73
Prepare APC for dismount		30	64	70	76
Move to PL directed location		57	83	54	77
Position hull down by G/CTL directions		37	–	69	79
Position hull down visually		39	–	70	79
Button up if needed		50	80	71	81
Monitor radios		50	84	69	79
Relay info to G/CTL or SL		65	85	50	76
Assist vehicle camouflage		63	–	53	80
Monitor radio		61	87	62	76
Feed ammo to G/CTL		36	63	74	69
Relocate vehicle		58	76	72	79
Move to assembly area		40	85	65	77
Position for remount		77	–	66	77
Prepare APC for remount		52	–	66	77

Table 2.3 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Assist reloading of APC		29	–	66	58
Drive concealed to disengage		68	–	63	67
Drive visually to formation		83	33	66	67
Drive under G/CTL or SL control to formation		65	33	63	69
Check gear and vehicle for damage		69	77	55	61
Check fuel and fluid supplies		57	80	81	85
Make necessary field repairs		82	66	77	83
Report vehicle readiness to G/CTL		81	71	83	75
GUNNER/CARRIER TEAM LEADER/(G/CTL)					
Receive orders and plans from PL		47	88	68	60
Review terrain maps with SL		68	87	84	60
Check condition of organic weapon		68	88	92	63
Check ammo supply		54	92	92	82
Check condition of NVDs		55	–	87	82
Check vehicle for equipment security		47	–	73	80
Assist loading of APC		42	–	77	66
Review SOPs and special orders with SL		53	–	77	74
Mount vehicle		66	–	77	62
Observe terrain for navigational purposes		68	–	87	92
Observe terrain for enemy presence		80	88	92	88
Observe PL hand signals		74	74	71	80
Observe PL flashlight signals		74	74	70	80
Intercom communicate with SL		82	–	83	74
Observe lead vehicle		82	77	77	74
Supervise water crossing		79	–	–	–
Detect direction of enemy ATs if encountered		84	82	66	76
Assist positioning of bounding vehicle		81	82	91	76
Fire from bounding vehicle	1	87	83	91	83
Overwatch bounding vehicle	2	87	82	91	83
Fire to protect bounding vehicle	3	90	87	64	83
Locate covered area		84	–		74
Direct positioning in covered area		82	85		74
Overwatch dismount	4	84	86	63	83
Direct positioning in hull down configuration		77	–	62	83
Mount NVDs if necessary		74	–	89	74
Receive PL regrouping plans		67	71	62	82

Table 2.3 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Identify TRPs		75	83	67	84
Establish range cards		83	–	67	84
Assist in vehicle camouflage		81	–	91	75
Fire 50 CAL at targets		82	87	89	85
Fire 50 CAL at areas	5	85	86	89	85
Maintain fire per range cards		80	–	89	76
Use NVDs		81	–	82	85
Coordinate firing with other vehicles & dismounted elements	6	86	87	90	85
Fire stationary		79	87	91	85
Fire in motion		83	85	93	89
Maintain knowledge of the squads' locations	7	88	83	92	87
Communicate with PL	8	91	83	92	86
Detect enemy movement	9	93	85	94	88
Determine need to relocate	10	89	85	90	74
Establish revised TRPs and range cards	11	92	89	90	84
Direct relocation or repositioning	12	90	90	94	80
Reposition to allow other SWs to fire as needed	13	89	87	94	80
Locate assembly area		77	–	91	83
Overwatch remount		77	–	88	84
Cover disengaging squads	14	91	91	91	84
Maintain concealed disengagement	15	89	–	91	80
Receive PL regrouping instruction		90	–	88	81
Proceed to regrouping		90	–	87	76
Fire to protect regrouping	16	89	–	89	80
Check organic weapon's condition		78	90	91	67
Make repairs to organic weapons		79	88	91	72
Check ammo supplies		82	86	90	75
Report vehicle readiness to SL	17	86	84	88	78
INFANTRY MANEUVER TEAM MEMBER (MTM)					
Receive orders and plans from PL		79	72	90	77
Check condition of weapons	18	88	87	90	77
Check ammo supplies		78	84	94	85
Check other gear as needed		78	80	84	87
Check NVDs		84	–	82	78
Load vehicle		35	–	77	80
Review SOPs and special orders with SL		60	82	82	80

Table 2.3 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Mount APC		73	82	73	83
Ride in APC		75	79	75	87
Remove web gear and securing for water crossing		67	-	-	-
Support mounted organic weapon firing		83	80	92	-
Detect targets in exposed position bounding vehicle	19	86	80	90	85
Fire weapons from bounding vehicle	20	85	83	92	85
Prepare to dismount		51	80	76	94
Execute dismounting procedure		59	-	76	94
Seek concealment		75	74	79	92
Plan fire effective positions	21	87	82	92	85
Coordinate weapon's locations	22	84	82	92	85
Carry weapons to locations		63	75	94	-
Reconnoiter subsequent positions		79	77	85	86
Mark routes between possible positions	23	86	76	86	88
Identify TRPs	24	84	78	86	85
Plan fire cover for possible relocations	25	86	83	89	88
Prepare range cards		81	-	89	83
Stake out range limits for weapons		77	-	89	81
Construct obstacles		73	-	91	82
Place obstacles		71	-	93	82
Plant mines		76	-	97	83
Camouflage		77	-	94	79
Learn routes to assembly area		79	-	82	76
Detect enemy arrival at effective distance		85	-	85	81
Fire on targets	26	89	82	94	81
Fire at areas	27	86	82	94	83
Communicate with SL via hand signals		82	68	77	81
Communicate with SL vocally		81	59	72	76
Communicate with PL by radio		81	89	91	82
Fire with NVDs	28	85	-	91	81
Feed enemy progress info to SL (or PL)		81	84	92	83
Collect gear for relocation		77	54	72	78
Cover movement to new position		86	82	77	83
Move rapidly to new positons via marked routes	29	89	80	77	88
Fire while relocating	30	88	84	80	83
Move to assembly area	31	88	-	80	86
Fire to cover move to assembly area	32	88	-	80	85
Fire from moving vehicle		88	74	81	82
Collect gear for remount		81	53	82	81

Table 2.3 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Remount rapidly		82	71	73	66
Cover other remounting members		84	66	74	81
Stow gear correctly		56	32	62	69
Support organic weapons to cover disengagement		84	–	81	73
Move to assembly area		81	–	75	82
Fire to cover movement to assembly area		89	–	75	82
Check gear for damage		71	–	64	50
Check ammo supplies		83	83	56	57
Report readiness to SL		86	81	58	70
SQUAD LEADER (SL)					
Receive orders and plans from PL		63	69	78	69
Review terrain maps with DR and G/CTL		60	68	79	72
Discuss material and weapons needs with PL		67	85	85	78
Check rosters for combat ready personnel for weapons needed by mission		52	76	81	69
Check conditions of NVDs		59	–	80	81
Supervise loading of vehicles		63	72	79	78
Inspect vehicles for equipment and organic security		48	70	80	78
Review SOPs and special orders with squads		53	70	81	81
Mount vehicle		59	69	72	83
Observe terrain for concealed movement routes		76	78	85	86
Observe terrain for enemy presence	33	87	74	88	86
Direct DR		78	82	78	86
Observe PL hand signals		68	75	66	80
Observe PL flashlight signals		70	75	66	80
Coordinate defensive squad fire		80	78	92	81
Communicate with PL as needed		82	79	79	76
Maintain proper movement configurations		83	77	78	82
Direct squad to dismount configuration		70	80	87	85
Conduct dismount		73	84	78	85
Receive sector assignments from PL		81	80	87	85
Assign positions		77	82	90	94
Establish communication network	34	87	80	82	88
Identify TRPs	35	90	82	62	92
Prepare range cards	36	90	–	89	92
Establish routes to subsequent position	37	93	82	90	92

Table 2.3 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Supervise obstacle and camouflage construction	38	85	76	90	82
Coordinate plan for assembly		87	80	79	83
Direct mounted vehicle to correct configuration		81	79	53	84
Coordinate squad firing in range		81	84	90	86
Communicate with PL on progress		71	82	80	83
Report enemy status to PL		80	72	90	83
Adjust firing as necessary	39	86	87	90	88
Coordinate squad relocation if necessary	40	85	87	91	88
Direct relocation fire	41	88	86	92	88
Make new range cards as needed	42	86	86	91	84
Direct movement to assembly area	43	88	86	91	88
Direct cover fire while moving to assembly area	44	87	83	89	91
Assign exposed fire team as needed when mounted	45	89	85	90	91
Coordinate fire needs per PL instructions while mounted	46	86	80	89	55
Direct remounting		83	72	72	83
Coordinate cover fire during remount		87	71	77	-
Direct squad movement during dis-engagement	47	88	68	79	88
Communicate with PL during dis-engagement	48	88	-	72	88
Direct proper movement to regrouping	49	87	-	72	86
Assess squad's infliction of damage on enemy		80	78	78	75
Assess squad's received damage		84	77	81	80
Report assessments to PL		65	78	84	67
PLATOON LEADER (PL)					
Receive orders and plans from company		53	62	79	72
Discuss orders and plans with platoon as needed		55	64	79	74
Discuss material and weapons needs with SLs		79	79	90	80
Discuss attachments		80	80	90	84
Conduct reconnaissance	50	88	55	92	93

Table 2.3 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Check accuracy of terrain maps	51	86	68	92	91
Check with SLs on readiness		83	55	86	86
Check with company on SOPs and special orders		82	55	86	84
Check on support fire availability	52	88	79	88	85
Mount APC		82	55	81	90
Communicate formation signals by hand to SLs		62	49	70	80
Communicate formation signals by flashlight to SLs		67	45	70	80
Identify terrain reference points		83	61	87	85
Communicate with company as required		80	79	81	85
Communicate by radio/wire to squads as necessary		78	80	91	88
Decide to engage unexpected fire or not	53	85	82	91	88
Direct mounted defense	54	84	--	91	88
Communicate with OPs	55	85	--	93	89
Request possible support fire requirements from company	56	84	83	94	89
Direct approach configuration to mission area		74	82	80	91
Process plan changes from company		72	82	84	90
Select positions for cover, concealment, observation, and fire	57	86	87	95	90
Communicate positioning to SLs		74	82	94	93
Select OP sights and posts		81	--	94	94
Post OPs		09	--	--	94
Establish inter-squad communication network	58	85	83	84	92
Assign locations to SLs	59	84	83	92	92
Select subsequent positions		72	81	94	92
Establish transition routes		81	79	92	92
Establish TRPs	60	84	82	96	92
Assign fire zones and targets	61	84	83	94	94
Position squad-detached APCs		83	82	92	92
Communicate with company and/or artillery as needed	62	85	86	94	90
Establish obstacles and camouflage needs		82	80	91	89
Direct preparations of squads		78	82	93	86
Choose assembly area		74	87	82	90

Table 2.3 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Instruct squads and G/CTLs on assembly plans		75	85	77	90
Inspect for readiness		69	81	78	81
Select firing configuration for mounted defense		84	82	82	81
Direct vehicle firing locations	63	87	82	85	89
Direct vehicle movement patterns	64	84	79	91	89
Coordinate firing using visual signals		80	74	90	80
Call indirect fire according to plans		81	85	92	88
Communicate with OPs and company as necessary	65	86	88	82	92
Decide when (or if) to relocate	66	88	88	84	93
Coordinate SL reports and G/CTL reports of enemy progress		80	68	82	92
Order relocation	67	88	89	79	93
Direct relocation cover	68	90	85	79	93
Coordinate changes in TRPs etc., after relocation	69	85	86	94	89
Order move to assembly area	70	87	83	84	93
Direct protective fire for move to assembly	71	88	82	87	93
Direct squad fire zones while mounted	72	87	80	87	91
Direct squad fire requirements while mounted	73	89	79	87	91
Direct remounting		74	62	78	86
Coordinate remounting protective fire		82	75	81	85
Direct disengagement	74	84	77	87	85
Call indirect fire required for disengagement	75	91	76	88	92
Recall OPs		09	–	92	–
Coordinate regrouping	76	86	67	89	88
Assess damage inflicted on enemy		83	54	89	77
Assess condition of platoon		88	54	75	79
Report mission status to company		72	81	75	78
Prepare for next mission		90	81	73	78

Table 2.4

Utility Ratings for Tank Tasks

TANK PLATOON LEADER (TK PL)	Critical Task No.	General Goals	Goals of Action 1	2	3
Receive plans and order from the CDR		53	72	90	72
Coordinate with other PL		53	72	86	71
Coordinate with FIST Chief		56	72	84	75
Request attachments		39	58	45	71
Issue warning order		55	72	50	75
Conduct reconnaissance		52	72	59	71
Confirm accuracy of terrain maps with ground		53	62	48	73
Coordinate with 81mm FO (Fire Planning)	1	78	72	86	75
Coordinate with ARTY FO (Fire Planning)	2	78	72	86	75
Select firing positions for tanks	3	82	86	86	75
Select observation posts	4	78	84	67	71
Select routes	5	66	80	44	76
Select alternate positions	6	82	86	84	75
Select supplementary positions	7	82	86	84	75
Check with TK CDRs to determine unit readiness		46	62	45	77
Order PLT forward		44	78	25	77
Direct tactical movement of PLT enroute		55	78	25	80
Communicate positioning of tanks to the TK CDRs	8	68	78	42	80
Use hand signals		47	80	42	64
Use flag signals		47	80	42	64
Operate intercom/radio	9	67	80	87	64
Discuss local security requirements with PLT		55	84	76	73
Discuss material and weapons requirements with TK CDRs		49	60	35	61
Order hot loop be established		52	61	73	73
Communicate obstacle and camouflage requirements to PLT		50	72	69	74
Supervise defensive preparations	10	78	76	79	73
Inspect for readiness	11	73	84	49	73
Approve TK CDRs' firing data	12	72	84	82	71
Approve FO's fire plan	13	73	84	90	73
Prepare PLT terrain sketch		47	75	71	77
Prepare PLT fire plan	14	73	82	81	73
Escort TM CDR during his inspection		49	62	66	71
Mount tank		24	50	61	55
Report enemy sightings		53	86	75	74
Acquire targets	15	75	90	88	74

Table 2.4 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Determine when to commence engagement	16	80	78	86	73
Order FO's to adjust fires	17	84	90	83	74
Control employment of coordinated PLT tank fire	18	78	90	87	73
Operate laser range finder	19	71	85	88	74
Operate CDR's cupola		58	85	75	64
Track targets using periscopes		58	85	77	64
Issue crew fire commands		64	90	87	73
Override gunner's traverse	20	72	85	79	74
Fire 50 CAL MG	21	67	90	90	74
Conduct immediate action to correct 50 CAL malfunctions		56	85	81	64
Decide when to (if) to relocate	22	70	88	81	79
Order relocation of vehicles		60	88	81	79
Control formations on the move	23	71	90	72	79
Communicate positioning to TK CDRs		57	90	69	79
Adjust indirect fire	24	87	90	90	78
Reload 50 CAL MG		59	85	77	67
Initiate radiological monitor		47	58	14	69
Troubleshoot sighting equipment		61	80	75	65
Replace sight components		51	80	33	65
Troubleshoot cupola malfunctions		43	80	71	65
Troubleshoot communications malfunctions		46	80	75	63
Troubleshoot electrical malfunctions		46	80	75	63
Encode/decode messages		53	85	30	63
Transmit situation reports to CDR		56	90	51	76
Issue fragmentary orders	25	85	95	87	76
Issue spot reports	26	75	90	79	71
Assess damage inflicted on the enemy		60	85	74	73
Assess status of TK PLT		63	90	76	79
Request resupply as needed		54	80	81	63
Request medical support as needed		51	80	35	63
Redistribute supplies		64	80	76	63
Prepare for next mission		58	75	66	63
Decontaminate self		42	77	54	77
Identify chemical agents		52	85	44	74
Escape from burning tank		24	37	10	75
Escape from overturned tank		24	10	10	75
Escape from sinking tank		24	10	10	75

Table 2.4 (Cont.)

TANK COMMANDER (TK CDR)	Critical Task No.	General Goals	Goals of Action 1	2	3
Receive plans and orders from TK PL		53	72	90	72
Coordinate other TK CDRs		53	72	85	71
Coordinate with gunner	27	79	90	88	74
Coordinate with driver	28	67	81	71	80
Cordinate with loader		51	90	88	73
Inspect tank engine		45	70	47	69
Inspect tank suspension and track		45	70	47	69
Inspect tank sighting and fire control		52	80	50	67
Conduct communications check		50	80	61	63
Inspect armament/ammunition		62	80	69	64
Control tank enroute		43	85	61	73
Interpret positioning instruction of TK PL		47	90	70	70
Occupy firing position	29	65	88	87	59
Implement local security instructions		52	80	62	70
Implement barrier and camouflage instructions		56	80	68	69
Direct clearing of fields of fire		59	85	72	71
Prepare tank range card		59	83	83	70
Select targets for main gun		55	90	81	74
Select targets for 50 CAL		56	90	82	74
Select targets for COAX MG		56	90	82	74
Plan fire control measures	30	86	90	85	71
Escort PL or TM CDR during inspection	31	70	73	75	76
Mount tank		58	75	71	69
Report enemy sightings	32	74	90	81	73
Acquire targets	33	72	90	90	71
Engage targets on order	34	72	90	90	71
Adjust indirect fires	35	88	90	90	74
Operate laser range finder	36	81	85	90	74
Operate CDRs cupola		58	85	75	64
Track targets		58	85	90	64
Issue crew fire commands	37	65	90	90	73
Traverse turret with override		72	85	89	74
Fire 50 CAL MG	38	67	90	90	74
Conduct immediate action to correct 50 CAL malfunctions		56	80	89	64
Decide when to (or if) relocate	39	66	90	88	79
Order relocation of vehicle		50	90	89	79
Control driver actions when moving	40	71	90	83	79
Reload 50 CAL MG as required		59	80	84	67
Troubleshoot sighting equipment		61	80	74	65
Troubleshoot fire controls		62	80	74	65
Troubleshoot communications equipment		46	80	74	63
Troubleshoot cupola malfunction		43	80	74	65
Encode/decode messages		53	80	39	63

Table 2.4 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Transmit status reports to TK PL		55	90	56	76
Transmit spot reports to TK PL	41	75	90	75	71
Assess damage inflicted on enemy		63	80	72	73
Assess status of tank		63	90	80	73
Request resupply as needed		47	80	67	63
Request medical support as needed		51	80	34	63
Redistribute supplies		47	80	71	63
Prepare for next mission		58	75	60	63
Decontaminate self		42	79	54	77
Escape from burning tank		24	10	10	75
Escape from sinking tank		24	10	10	75
Escape from overturned tank		24	10	10	75
TANK GUNNER (TK GR)					
Assist TK DR in vehicle maintenance		45	50	42	79
Boresight COAX MG		50	80	49	73
Boresight main gun		55	80	59	73
Zero COAX MG		50	80	49	73
Zero main gun		55	80	59	73
Operate tank intercom		56	82	77	77
Prepare tank range card with TK CDR		52	83	85	72
Operate ballistics computer		58	90	85	72
Operate azimuth indicator		8	90	85	72
Identify target reference points		59	79	75	70
Identify map symbols on the ground		59	65	61	76
Determine fields of fire for main gun		61	87	85	71
Determine fields of fire for COAX MG		62	87	85	71
Advise TK CDR of deadspace in fields of fire		57	78	76	73
Acquire targets	42	84	88	89	74
Track targets	43	84	88	89	74
Receive fire commands from TK CDR	44	82	81	89	73
Fire main gun	45	82	90	89	73
Fire COAX MG	46	81	90	89	73
Diagnose turret/maingun/traverse malfunctions		57	75	78	74
Diagnose sighting and fire control malfunctions		57	85	79	74
Diagnose recoil malfunctions		57	85	74	74
Diagnose commo malfunctions		51	75	71	73
Measure radiation		51	49	46	74

Table 2.4 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Decontaminate self		48	49	46	77
Escape from burning tank		24	10	10	76
Escape from overturned tank		24	10	10	76
Escape from sinking tank		24	10	10	76
TANK LOADER (TK LDR)					
Assist TK DR in vehicle maintenance		45	50	42	79
Load ammunition on tank		53	85	84	73
Operate tank intercom		53	80	82	73
Load COAX MG	47	72	85	90	73
Load 50 CAL MG	48	72	85	90	73
Handle main gun rounds	49	82	90	83	74
Load selected rounds	50	82	95	90	74
Conduct WPN safety checks	51	77	90	85	74
Conduct communications operation checks	52	76	80	85	76
Set head space and timing on 50 CAL MG	53	72	66	77	74
Inventory ammunition		67	70	61	73
Operate breach mechanism	54	76	90	85	74
Operate fire/safety switch	55	76	90	80	74
Advise TK GR when COAX and main gun can fire	56	77	90	85	73
Conduct immediate action to correct COAX malfunction	57	72	85	72	74
Unload nonoperational main gun rounds	58	71	85	72	74
Dispose of expended round cannisters		22	60	50	69
Advise TK CDR of ammo status		59	80	80	76
Assist TK CDR with observation		52	45	66	68
Camouflage tank		38	54	45	69
Dismount tank for local security		60	49	47	73
Install/remove field phones		52	58	51	64
Install/remove wire		52	58	51	64
Erect obstacles		59	67	67	65
Diagnose breach malfunctions		57	71	79	64
Emplace/recover mines		64	68	67	65
Measure radiation		51	41	46	74
Decontaminate self		48	41	46	77
Escape from burning tank		24	10	10	76
Escape from overturned tank		24	10	10	76
Escape from sinking tank		24	10	10	76

Table 2.4 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
TANK DRIVER (TK DR)					
Inspect tank engine		45	80	31	79
Inspect tank track		45	80	31	79
Assist crew in maintenance		45	50	31	79
Install/remove engine		45	50	31	79
Install/remove track		45	50	31	79
Drive tank on level terrain		53	64	69	80
Drive tank on steep grades		53	64	69	80
Drive tank during periods of darkness or limited visibility		61	66	74	80
Drive tank on slide slopes		53	64	69	80
Drive tank over water obstacles		53	66	59	80
Camouflage vehicle		38	72	45	77
Drive tank in mud/snow/sand/ice		53	66	74	80
Drive tank in convoy		53	20	17	70
Install periscopes		50	76	23	70
Install IR periscope		50	77	23	70
Conduct before/during/after operations checks		49	90	71	79
Prepare tank for normal operations		49	77	77	79
Prepare tank for water operations		50	77	77	79
Prepare tank for cold weather operations		49	77	77	79
Prepare tank for hot weather operations		49	77	77	79
Operate intercom		50	79	71	74
Refuel tank		52	65	33	74
Dismount tank for local security		55	79	67	65
Erect obstacles		59	77	67	63
Emplace/recover mines		64	76	67	63
Measure radiation		51	68	46	74
Decontaminate self		47	49	46	77
Decontaminate tank		42	49	46	79
Escape from burning tank		24	10	10	76
Escape from sinking tank		24	10	10	76
Escape from overturned tank		24	10	10	76
Prepare tank for recovery		48	75	44	79

Table 2.5

Utility Ratings for FIST Tasks

FIST CHIEF	Critical Task No.	General Goals	Goals of Action 1	2	3
Receive orders and plans from TM CDR	1	65	70	14	69
Coordinate with TM CDR	2	65	69	22	70
Coordinate with PLs	3	64	69	40	62
Coordinate with FSO	4	61	69	33	28
Coordinate with 4.2" FO		47	63	22	53
Coordinate with ARTY FO TMS		53	69	86	62
Coordinate with FS NCO		54	63	87	84
Coordinate with 4.2" FDC		56	63	44	47
Coordinate with 81mm FDC		56	44	44	34
Coordinate with DS BAT FDC		56	69	92	49
Conduct observation post reconnaissance		57	71	56	81
Conduct route reconnaissance		37	51	48	79
Confirm accuracy of terrain maps		37	25	44	68
Identify key TRPs		49	29	45	67
Select OPs	5	59	66	87	93
Identify targets		54	68	83	76
Transmit target intelligence		55	51	71	62
Establish TRPs		56	59	69	67
Establish FPFs		58	72	60	83
Establish TGPs		57	71	67	76
Plan WPN SYS, round, FUZE, MOE, & MOC for each target	6	61	66	74	56
Use field binoculars		58	66	84	74
Operate NOD		58	66	84	74
Operate laser locator-designator	7	60	66	86	73
Operate digital message device		58	66	75	72
Use compass		54	48	60	56
Operate radio		54	55	79	61
Operate field telephone		57	68	72	9
Establish communications with the supported CDR (wire & radio)		56	62	77	14
Establish communications with the ARTY FOs (wire & radio)		51	6	79	26
Establish communications with the ARTY FDC (wire & radio)		51	69	79	26
Use CEOI (book)		29	29	24	11
Orient for direction	8	64	90	76	73

Table 2.5 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Determine exact position on the ground	9	59	90	76	85
Prepare a terrain sketch		54	64	75	81
Prepare initial target list		54	64	71	90
Prepare initial target overlay		54	64	72	90
Transmit target list to FSO		55	19	33	70
Encode target information using KAL61		66	19	27	60
Transmit hasty target lists using gridded thrust line		57	19	27	70
Make use of CEOI extract of the gridded template coding table		56	19	27	40
Acquire targets		55	81	82	82
Determine target range		45	81	85	82
Make appropriate call for fire (grid, polar, shift, etc.)		56	79	92	82
Observe effects of fire		58	79	81	85
Correct for range		56	81	73	78
Correct for deviation		56	79	69	78
Adjust corrective fires	10	59	81	73	81
Engage targets of opportunity	11	59	85	69	81
Adjust CLGP (laser)	12	62	86	70	80
Adjust smoke mission		56	79	43	85
Adjust open sheaf mission		57	77	43	73
Adjust converging sheaf mission		54	62	69	60
Adjust irregularly shaped target		54	73	71	60
Determine when to request a fire for effect		58	80	77	67
Determine when to request end of mission	13	67	80	77	67
Adjust registration mission		56	34	21	5
Adjust ICM mission	14	64	82	70	76
Adjust counterfire mission	15	63	84	45	70
Advise CDR in use of direct fire WPNS to suppress EN		56	77	64	75
Adjust immediate suppression	16	59	75	64	75
Monitor FO CFF		59	47	33	64
Approve FO CFF	17	67	53	54	72
Redirect FO CFF	18	62	68	84	83
Request FSO provide GS artillery support	19	66	79	84	83
Adjust TACAIR	20	65	86	84	81
Adjust high burst	21	67	71	50	66
Adjust attack helicopters	22	65	86	84	81
Adjust naval gun fire		64	86	84	81
Adjust mortars	23	62	62	61	81
Mount APC		54	10	42	58
Adjust illumination	24	62	55	75	52

Table 2.5 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Adjust danger close	25	60	81	69	82
Adjust fire by sound		54	68	58	64
Adjust multiple missions	26	65	82	71	79
Direct actions of FS NCO		57	52	74	79
Direct actions of RTO		54	26	46	74
Direct actions of driver		57	18	19	68
Report target engagement results	27	63	78	46	28
Order relocation of FIST	28	60	85	67	93
Relay calls for fire	29	67	81	79	80
Talk inexperienced observer through CFF		58	81	79	80
FORWARD OBSERVER (FO)					
Receive plans and orders from FIST Chief	30	66	77	57	72
Receive plans and orders from PL	31	65	81	92	84
Coordinate with FIST Chief	32	62	72	43	52
Coordinate with PL	33	65	81	78	81
Coordinate with RTO		54	40	46	51
Coordinate with FDC	34	61	69	46	49
Conduct OP reconnaissance		57	39	60	67
Conduct route reconnaissance		37	39	39	84
Confirm accuracy of terrain maps		37	34	34	61
Identify key TRPs		49	34	35	61
Select OPs	35	59	78	85	86
Identify targets		54	65	88	73
Transmit target intelligence		53	48	71	69
Select TRPs		56	57	61	76
Establish FPs		58	72	78	89
Establish target groups		57	77	87	87
Use field binoculars		58	73	82	78
Operate NOD		58	73	82	78
Operate laser locator-designator	36	60	58	88	78
Operate digital message device		58	82	82	78
Use compass		54	58	72	68
Operate radio		54	59	82	73
Operate field telephone		57	56	77	50
Establish communications with FDC		51	73	76	68
Use CEOI		29	57	17	47
Orient for direction	37	64	90	85	82
Determine exact location on the ground	38	59	90	85	82
Prepare terrain sketch		54	64	62	82
Prepare target list		54	64	56	82
Prepare target overlay		54	64	56	82
Encode target information using KAL61		56	64	15	77
Transmit target list		55	64	26	82

Table 2.5 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Transmit hasty target list using gridded THRUSTLINE		57	64	29	82
Make use of CEOI extract on the gridded template coding TB		57	64	25	72
Acquire targets	39	59	69	92	81
Determine range of target	40	59	69	88	81
Determine direction of target	41	59	69	88	81
Place appropriate CFF (grid, polar-plot, shift, etc.)		56	85	91	81
Observe effects		58	85	81	76
Correct for range		56	92	83	81
Correct for deviation		56	87	82	79
Adjust fire		58	87	85	81
Engage targets of opportunity	42	59	87	80	89
Adjust CLGP	43	59	92	79	87
Adjust smoke mission		56	87	49	89
Adjust open sheaf mission		57	65	51	85
Adjust converging sheaf mission		54	65	79	86
Adjust irregularly shaped target mission		54	66	66	84
Determine when to request fire for effect		58	79	91	85
Determine when to request end of mission	44	67	50	73	85
Adjust registration mission		56	52	21	51
Adjust ICM mission	45	64	79	70	83
Adjust counterfire mission	46	63	57	45	87
Adjust immediate suppressive fire	47	59	74	64	87
Adjust TACAIR	48	65	85	84	87
Adjust high burst mission	49	67	71	50	71
Adjust attack helicopters	50	65	86	84	87
Adjust naval gunfire		64	86	84	87
Adjust mortars	51	62	63	61	87
Adjust illumination	52	62	55	75	51
Adjust danger close	53	60	84	69	90
Adjust fire by sound		54	68	58	63
Adjust multiple mission	54	65	85	71	81
Report target engagement results	55	63	78	46	28
Relay calls for fire	56	67	86	79	80
Talk an inexperienced observer through a call for fire		58	81	79	80

Table 2.5 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
FIRE SUPPORT NCO (FS NCO)					
Receive plans and orders from FIST Chief	57	66	67	55	90
Coordinate with FIST Chief		56	63	65	90
Supervise FIST driver		55	14	10	70
Supervise FIST RTO		57	14	39	63
Request FIST rations		30	5	5	15
Request FIST water		30	5	5	15
Request FIST fuel		30	5	5	15
Request FIST ammo		32	7	5	15
Procure FIST rations		32	5	5	15
Procure FIST water		32	5	5	15
Procure FIST fuel		32	5	5	15
Procure FIST ammo		32	7	5	15
Issue rations		31	5	5	15
Issue water		32	5	5	15
Issue ammo		32	7	5	15
Supervise maintenance activities		27	10	5	35
Supervise camouflaging activities		51	22	21	16
Monitor communications on mortar PLT fire control nets		47	69	58	71
Record target lists sent by mortar FO's to FDC		58	75	37	71
Assist FIST Chief consolidate company target list		58	75	38	71
Assist FIST Chief prepare target overlay		58	75	38	75
Coordinate with mortar PLT FDC Chief		54	76	74	61
Act as vehicle commander		38	34	26	71
Redirect FO CFFs	58	72	79	81	84
Mount vehicle		15	11	11	67
Prepare range card		47	[illegible]	14	49
Coordinate local security		48	51	18	53
Report results of mortar engagements to FIST Chief		57	69	44	63
RADIO TELEPHONE OPERATOR (RTO)					
Operate radio		52	83	82	79
Operate field telephone	59	60	77	70	64
Install remote communications device		58	76	42	50
Install secure communications device		58	77	42	48
Lay wire (WD/1)		56	76	42	49
Monitor radio communications		45	62	44	69
Monitor field telephone communications		45	62	44	63
Operate switchboard		43	58	42	54
Transmit messages		55	83	52	54

Table 2.5 (Cont.)

	Critical Task No. General Goals	Goals of Action 1	2	3
Record messages	26	28	20	44
Repeat CFFs	40	83	81	65
Be prepared to adjust fire if ordered to do so	54	87	90	87

Table 2.6

Utility Ratings for Artillery Battery Tasks

	Critical Task No.	General Goals	Goals of Action 1	2	3
BATTERY EXECUTIVE OFFICER (XO)					
Serve as acting battery CO		40	82	82	88
Supervise battery when it occupies a firing position	1	80	82	89	89
Lay the battery when it occupies a firing position	2	78	90	89	89
Measure and report directions	3	68	66	66	79
Determine minimum quadrant elevation		60	66	66	79
Supervise section chiefs during boresighting		40	63	66	69
Control fire of the battery	4	83	90	90	89
Insure before, during, after DPS maintenance is performed		35	48	30	64
Insure area improvements are completed in accordance with BC's order		44	74	79	88
Insure sections store, segregate, and protect ammo	5	79	58	66	71
Render XO's report to FDC		56	48	90	60
Insure intra-battery communications are established		65	77	72	62
Insure safe firing practices are observed in battery		40	29	34	35
Insure each section chief knows location of his supplementary position		62	72	84	89
Insure each section chief has reconned route to supplementary position		62	72	84	89
Coordinate with ISG to determine fire sectors for each howitzer		60	72	85	89
Supervise section chiefs in preparing range cards		52	52	75	79
Insure ammo is distributed in accordance with anticipated needs of FDC	6	75	62	74	76
HOWITZER SECTION CHIEF (HOW SC)					
Insure that weapon is properly emplaced	7	72	84	81	80
Insure weapon is ready for action	8	72	84	83	80
Lay weapon	9	73	84	90	80
Select aiming points for gunner	10	73	70	75	67
Site to the crest	11	77	70	75	67

Table 2.6 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Order when to boresight	12	77	70	65	10
Order azimuths marked	13	77	63	78	10
Order the prefire checks performed	14	68	63	65	10
Position local security		51	61	78	83
Supervise camouflaging		44	10	40	83
Supervise construction of field fortifications		55	22	44	85
Measure and report site to the crest	15	77	43	75	61
Determine piece to crest range	16	77	43	75	61
Supervise section during firing	17	83	84	90	85
Observe and check functioning during firing		44	15	61	75
Report observed malfunctions or errors		44	15	61	75
Inspect ammo storage, segregation, and protection		50	15	5	75
Inspect maintenance performed		60	5	5	22
Insure on board ammo and gear is stored properly		53	10	5	22
Prepare range cards for all section crew-served WPNS		53	56	41	72
Control howitzer fires during direct fire engagement		50	86	68	90
Organize section for continuous operation		56	62	70	76
Maintain firing and maintenance records		24	5	5	24
GUNNER (GR)					
Lay cannon on initial direction of fire with aiming circle	18	75	87	86	89
Lay cannon on initial direction of fire with compass	19	75	87	86	89
Lay cannon on initial direction of fire with distant aiming point	20	75	87	86	89
Lay cannon on initial direction of fire by reciprocal lay of another cannon	21	75	87	86	89
Verify direction of fire with reciprocal check as control piece	22	75	87	80	84
Verify direction of fire with reciprocal check as adjacent piece	23	75	87	80	84
Verify direction of fire with reciprocal check using lighting device	24	75	87	80	76
Align collimater/aiming posts		64	64	59	62

Table 2.6 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Boresight the panoramic telescope with the MAO alignment device	25	72	64	78	87
Boresight the panoramic telescope with a distant aiming point	26	72	64	78	87
Boresight the panoramic telescope with the collimater	27	72	64	78	87
Boresight the panoramic telescope using the testing target	28	72	64	78	87
Set/lay cannon for deflection	29	79	87	84	89
Sight on a target during direct fire with panoramic telescope		52	90	82	90
Refer the piece	30	75	64	80	71
Determine the altitude of a point using a map		30	5	6	27
Convert grid to magnetic azimuth		30	5	6	79
Convert magnetic to grid azimuth		30	5	6	79
Measure an azimuth on a map using a protractor		34	5	6	79
Measure ground distance on a map		34	5	6	79
Locate an unknown point on a map by intersection		30	5	17	79
Locate an unknown point on a map by resection		30	5	5	79
Orient a map with a compass	31	74	5	10	89
Orient a map by terrain association	32	74	5	10	89
Determine present location by terrain association	33	79	5	6	89
Select movement route using a map		48	5	11	89
Navigate from one point to another using map and compass		48	5	16	89
Locate a point on a map using the military grid-ref system	34	72	5	6	84
Lead a security patrol		41	5	20	58
CREWMEMBER (CM)					
Prepare a position to receive/emplace a cannon		65	38	87	77
Guide vehicles using arm and hand signals		56	29	87	77
Guide vehicles using flashlight signals		56	29	87	77
Engage/disengage tube travel lock		23	5	6	49
Emplace/recover spades		35	5	15	49
Lay communications wire to FDC	35	82	38	35	35
Connect wire to telepost terminal on vehicle	36	82	38	35	35
Emplace/recover collimater	37	71	29	35	18

Table. 2. 6 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Emplace/recover aiming posts	38	71	29	35	37
Boresight the direct fire telescope using distant aiming point		56	29	87	39
Transport cannon ammo onto the vehicle		61	29	81	71
Prepare cannon ammo for helicopter resupply		65	34	81	72
Operate material handling hoist on M 548 cargo		61	29	77	71
Store ammo at a cannon position	39	66	29	74	67
Protect the ammo		56	29	74	69
Segregate the ammo by type		56	20	54	56
Monitor and relay fire commands	40	85	85	89	89
Prepare ammo for firing	41	85	85	80	76
Recognize ammo types by color coding	42	85	65	60	9
Identify fuzes and fuze wrenches by type	43	85	65	80	9
Fuze the projectile	44	85	85	70	17
Set the fuze using the proper fuze setter	45	85	85	70	21
Prepare propellant charge	46	85	85	80	21
Set/lay cannon for quadrant with the range quadrant	47	75	65	80	70
Measure the quadrant with the range quadrant		65	65	73	70
Sight on a target with a direct fire/elbow telescope		55	75	76	82
Load a "prefixed" round		57	79	76	65
Load a "separately-loaded" round		57	79	76	65
Ram a projectile with the power rammer		57	79	67	55
Fire the cannon		57	90	89	90
Place unfired powder increments in the powder pit		23	5	5	13
Clear powder chamber		20	5	5	5
Command "check fire" when unsafe conditions exist		20	10	5	16
Clear and maintain victim's airway		20	5	5	35
Stop bleeding		20	5	5	35
Treat for shock		20	5	5	35
Decontaminate casualties		20	5	5	35
Recognize/mark CBR hazards		33	5	5	60
Mask on signal		27	5	5	60
Decontaminate self, equipment, supplies		27	5	5	78
Install and operate TA312/PT		46	45	71	5
Operate vehicle intercom		27	45	66	73
Lay and maintain wire		46	45	71	5
Measure magnetic azimuth with M2 compass		30	5	5	79
Measure ground distance by pacing		15	5	5	79
Report enemy information		61	82	78	83
Process and evacuate captured enemy		33	5	5	43
Identify personnel using challenge and password		32	5	5	33
Camouflage self, weapon, equipment		56	5	5	74

Table 2.6 (Cont.)

	Critical Task No.	General Goals	Goals of Action 1	2	3
Construct individual defensive position		45	5	87	58
Prepare range card		53	5	87	70
Cross danger areas		41	5	5	84
Use M16 rifle		48	81	76	75
Prepare to fire and engage target with LAW		49	81	75	80
Use M203 grenade launcher		49	81	76	80
Emplace/recover claymore mine		48	81	76	74
Use hand grenade		40	75	76	55
Operate M60 MG		48	81	79	79
Operate CAL 50 MG		48	82	79	79
Engage ground targets with M60 MG		48	82	79	79
Engage ground targets with CAL 50 MG		48	32	79	79
Engage aerial targets with M60 MG		48	79	79	78
Engage aerial targets with CAL 50 MG		48	79	79	78
Inspect and clean aiming posts lighting devices		22	5	5	5
Clean tube and chamber		29	5	5	5
Clean chamber evaculator, valves, muzzle brake		29	5	5	5
Operate M109A1 Howitzer under unusual conditions	48	84	92	88	86

Applying MAUT to Specific Platoon Action Goals

Specific platoon action goals were developed on the basis of the involved scenario by the program's military consultant. These goals were designed to be consistent with each of the three different platoon actions included in the scenario which formed the backdrop for the present work. Each platoon action produced four goals. The importance of each platoon action goal was rated and scaled using the method described for the general mission goals by the same person who scaled the general mission goals.

The first specific platoon action involved repelling an assault from a battle position. The derived goals of this action and the results of ordering and scaling them are presented in Table 2.7.

Table 2.7

Importance of Goals for Four Types of Units in Repelling an Enemy Assault From a Battle Position

Goal	Unit Type: Mechanized Infantry	Armor (Tanks)	FIST	Artillery
Block the penetration	.31	.30	.40	.20
Destroy or eject enemy	.28	.40	.30	.40
Reduce penetration	.25	.20	.20	.30
Regain lost portion of BP	.16	.10	.10	.10
Σw_j =	1.00	1.00	1.00	1.00

The second specific platoon action involved defense of a strongpoint. The derived goals of this action, ordered from most to least important, are presented as Table 2.8.

Table 2.8

Importance of Goals for Four Types of Units in Creating and Defending a Strongpoint

Goal	Unit Type: Mechanized Infantry	Armor (Tanks)	FIST	Artillery
Retain or deny terrain to enemy	.40	.20	.10	.10
Gain time	.30	.10	.20	.20
Wear down enemy attack force	.20	.40	.40	.40
Destroy weakened enemy force	.10	.30	.30	.30
Σw_j =	1.00	1.00	1.00	1.00

The third specific platoon action involved moving forces to occupy another battle position. The derived goals of this action are presented in Table 2.9 along with the results of the scaling of their importance.

Table 2.9

Importance of Goals for Four Types of Units in Disengaging and Occupying a New Battle Position

Goal	Unit Type			
	Mechanized Infantry	Armor (Tanks)	FIST	Artillery
Maintain ability to move	.40	.40	.30	.30
Control essential terrain	.30	.10	.10	.10
Maintain tactical objective	.20	.20	.20	.20
Preserve forces	.10	.30	.40	.40
Σw_j	= 1.00	1.00	1.00	1.00

Weighting Tasks on Specific Platoon Action Goals

Next, employing the same methods as described above for the general mission goals, the aggregate utility of each task was derived for each specific platoon action. There was now on hand an aggregate utility value for each task relative to the general mission goals and to the goals of each of the specific platoon actions. The aggregate utility of each task for the goals of each platoon action is shown in the last three columns of Tables 2.3, 2.4, 2.5, and 2.6.

Critical Task Identification

The next analytic step involved combining these data sets to produce lists of the most critical tasks for each of the positions and units under study.

In order to establish a decision rule for the classification of tasks as critical, a frequency distribution was developed using aggregate utilities of tasks on general mission goals and on the goals of the three platoon actions of the mechanized infantry, armor (tanks), artillery, and FIST. Decision axes were places at different positions to define areas of "low," "medium," and "high" importance for each of the types of unit. To define "low," "medium," and "high" importance tasks, the decision axes were transferred from the pooled distributions to the same points on the distributions developed from the analysis of general mission goals. Accordingly, all three defensive (platoon) actions were dealt with in the same way. Since there were four distributions for each type of unit and a total of four units, 16 distributions were involved in the importance assignment process. Table 2.10

summarizes the decision criterion for each of the four types of unit, i.e., the value that had to be achieved by each task when rated against the general mission and the specific platoon action goals. In order for a task to be classified as critical, a "high" aggregate utility rating was required for the task on the general mission goals and on at least one of the three sets of specific platoon action goals.

Table 2.10

Criteria Used to Identify a Task as Critical for Each of Four Types of Unit

Unit	General Mission Goals	Specific Platoon Action Goals
FIST	M*	M + 10
Armor (Tanks)	M	M + 10
Artillery	M + 10	M + 10
Mechanized Infantry	M + 6	M + 6

*M = Mean

A total of 241 critical tasks was identified in this way.

Mechanized Infantry

A total of 76 critical mechanized infantry tasks, divided across four positions, was produced from the full set of 263 mechanized infantry tasks by this conjoint classifcation procedure. The method failed to produce any critical tasks for the vehicle driver. The critical tasks, so identified are given in the first column of Table 2.3.

Armor (Tanks)

A total of 58 critical tasks, divided across four positions, was produced from the full set of 218 tank crew tasks by this conjoint classification procedure. The method employed here failed to produce any critical tasks for the tank driver. The tasks identified as critical are identified in the first column of Table 2.4.

FIST

A total of 59 critical tasks, divided across four positions, was produced from the full set of 188 FIST tasks by this conjoint classification procedure. These tasks are identified in the first column of Table 2.5.

Artillery

A total of 48 critical tasks, divided across four positions, was produced from the full set of 137 artillery tasks by this conjoint classification procedure. The method employed here made no distinction among 155 mm crew members. The tasks identified as critical for the artillery are given in the first column of Table 2.6.

Discussion

Clearly, now that critical tasks of soldiers have been isolated within the context of a specific scenario, the effect of the environment on human performance can also be more clearly specified at least for the scenario involved.

The design of military training programs, jobs, and environmental settings to match the capacities and limitations of the soldier, when possible, is a desirable goal. An analysis such as that conducted here represents the first step toward understanding the most critical problems associated with the relationship of the soldier to his environment. The companion volumes apply the information developed here to clarify the anticipated stressor effects on the critical tasks within the existing scenario and to guide the management of human resources in continuous operations.

While the general purpose was to use the results of the present analysis to identify tasks which form a basis for isolating shortfalls associated with active defense operations, other possibilities also come to mind for such job information. The information can be used:

1. as a basis for training program development
2. as a basis for job evaluation programs
3. as a basis for counseling individuals
4. to develop selection programs
5. to develop computer simulation models of the active defense.

CHAPTER III

MATHEMATICAL MODELING APPROACHES TO PROJECTING PERFORMANCE DEGRADATION

The preceding chapters, together with the parallel report of the prior year (Pfeiffer et al, 1979), provide the essential background for this chapter. The salient points to be recalled are that a realistic scenario was developed of an active defense against a mid European breakthrough attack. The scenario assumes continuous operations over some five days (120 hours). Four types of adverse factors are inherent in continuous operations: (1) fatigue resulting from sleep loss, (2) disrupted diurnal rhythms, (3) reduced light levels and similar visibility factors, and (4) "mental" stress. Basic abilities are critical to varying degrees and in various combinations to the performance of each critical task listed in the preceding chapter.

Data Underlying Model Parameters

The parameters of the models described below were derived from empirical data albeit over several intermediate steps. The first of these steps was based on the survey of literature extended in Chapter I and in Pfeiffer et al (1979). The aggregate of information and data extracted made possible: (1) a determination of the adverse factors in continuous operations which act to depress critical abilities, and (2) an assessment of the degree of the impact. The latter assessment was made possible by cited data, graphs, curves, tables, etc. in the literature, at least to the extent of determining whether a significant depressive effect would be manifested. "Significance" was defined as a likely shrinkage of the ability in question by 20%

The ways in which the adverse debilitating factors in continuous operations impact upon and depress the critical abilities is summarized in Table 3.1. According to the Table 3.1 analysis, Fatigue affects 6 of the 9 abilities, Diurnal Rhythms affect 2, Light Level/Visibility affects 4, and Stress affects 4. The bottom row summarizes the total number of impacts on each separate ability or the worst case possible. The maximum number of possible impacts in the worst possible case is 16.

A determination was made as to whether or not an impact (i.e., a 20% depression of a given ability) would, in fact, occur in each critical task (listed in Chapter II) carried out in each type of defensive (platoon) action included in the overall scenario. Since such a determination requires a judgment as to the severity of conditions in each type of defensive action as well as an interpretation of background data, it was made by a team of two experienced, professional scientists and a military expert. Both psychologists were familiar with and had available the extracted data and information from the literature survey. The military advisor had previously developed the details of the scenario. He also possessed considerable operational military experience.

Table 3.1

Summary of Factors Degrading Critical Abilities

Degrades	Communication	Dynamic Precision	Hearing	Memory	Numerical Facility	Orientation	Perceptual Speed	Reasoning	Vision
Fatigue (Sleep Loss)			✓		✓	✓	✓	✓	✓
Diurnal Rhythm					✓			✓	
Light Level/Visibility		✓	✓			✓			✓
Stress	✓			✓			✓	✓	
Total Impacts on Ability	1	1	2	1	2	2	2	3	2

GRAND TOTAL 16

Each of the three judges worked independently in assessing the probable degree of impact on each ability in each defensive (platoon) action from each source. An entry in a table was made only if a given impact was thought to produce a depression of the given ability of 20% or more. After each working table (tasks by abilities affected by each adverse factor) was completed by each judge, agreement among the three judges was established. An entry into the final table of impacts was made only after a consensus of judgment was reached among the judges.

Tables 3.2, 3.3, 3.4, and 3.5 present, respectively, these final judgments for mechanized infantry, armor (tanks), Fire Support Teams (FIST), and artillery. The columns in each table are labeled as to type of adverse (impacting) factor and abbreviations are given for each of the critical abilities (e.g., V for Vision, H for Hearing, etc.). Entries of 1, 2, and 3 in the cells of the table refer to impacts produced in defensive (platoon) actions: 1 = repel an assault from a battle position, 2 = create and defend a strongpoint, and 3 = disengage and occupy a new battle position. Phrased differently: an entry of "1" means that defensive (platoon) action 1 engenders conditions such that the given impacting factor will depress the given critical ability for a given task by 20% or more.

Table 3.2

Mechanized Infantry: Summary of Significant Depressions of Critical Abilities

	TASK NO.	FATIGUE						DIURNAL RHYTHM		LIGHT LEVEL				STRESS			
		V	H	NF	R	PS	O	NF	R	V	H	DP	O	M	R	PS	C
GUNNER/ CARRIER TEAM LEADER	1	12	12			12				12	12					12	
	2	12				12				12	12		12				
	3	1				1				1	1					1	
	4	1								1	1						
	5																
	6	3	1 3			1 3	1 3			123	1 3	1 3		1 3		1 3	
	7						123						123	1 3			
	8																123
	9	123	123			123				123							
	10			12	12				1						1		
	11			12	12	1	12	12	12	12			12	1	12	12	
	12			1	1				12	12	1			1	1		12
	13						1	1	1	12			12		1		1
	14	12	12	1	1	12		12	12	12					1	12	
	15						2						2	2	2		
	16	2		2	2			2	2	2					2		
	17																
MANEUVER TEAM MEMBER	18									12		12			1		
	19	23	23			23				23	23			3		3	
	20	123								123		123					
	21			23	23			3	3						3		
	22		2				2				2	2		2			2
	23						3			3		3					
	24						3			3			3	3		3	
	25			123	123			3	3					3	1 3		
	26	2	2			2				2				2		2	
	27																
	28	2				2								2		2	
	29					3				3			3			3	
	30	1	1			1				1		1		1		1	
	31									3			3				
	32	3	3			3				3				3		3	
SQUAD LEADER	33	3	3			3				3	3					3	
	34				3										3		3
	35	3					3			3			3				
	36	23		23	23		23	3	3	3			23		3		
	37	3		23	23		23	3	3	3			23				
	38			2	2												
	39	123	123	1 3	1 3	1 3		123	123	123	1 3			1 3	1 3	1 3	1 3
	40			123	123		123	123	123				123	3	3		3
	41	123	123	123	123		12	123	123	123	1 3		12		1 3		
	42	1 3		12	12		12	1	1	12			12				
	43		123				123	3	3				123	1 3	1 3		1 3
	44	123	123	123	123	123		123	123	123	123			123	123	123	1 3
	45			123	123				1 3						123		
	46			2	2				2						2		2
	47		3	3	3		3		3	3	3		3		3		3
	48		3							3	3						3
	49			3	3		3		3			3		3	3		3
PLATOON LEADER	50						23	23	23	23			23				
	51						3			23			23			3	
	52																
	53			23	23				23						3		
	54		23	23	23	3		3	23	23	23			23	23	23	23
	55																3
	56			123	123		1 3	1 3	123				123	123	123		
	57			123	123	1 3			1 3	1 3					123		3
	58			3	3				3						3		
	59						1 3						123				
	60	3		3	23	3	3		3				23	3	3	3	
	61			1 3	1 3			1 3	1 3				3		3		1 3
	62																1 3
	63			3	3			3	3	3	3		3	3	3		3
	64			3	3		23		23				23		3		3
	65																3
	66				1 3				1 3						3		
	67																3
	68		1 3	1 3	1 3			3	1 3	1 3	1 3			1 3	1 3		1 3
	69			1 3	1 3	1 3	123	1 3	1 3				123	123	123	123	1 3
	70																3
	71	3	3										3	3			3
	72				3			3	3	3	3			3	3		3
	73	3	3		3	3			3					3	3		3
	74				3		3		3	3	3		3		3		3
	75						3						3				3
	76			3	3		23		23				23		23		3

Table 3.3

Armor: Summary of Significant Depressions of Critical Abilities

	TASK NO.	FATIGUE						DIURNAL RHYTHM		LIGHT LEVEL				STRESS			
		V	H	NF	R	PS	O	NF	R	V	H	SP	O	M	R	PS	C
PLATOON LEADER	1								3				3		3		3
	2								3				3		3		3
	3				123		1 3		12						1 3		
	4				1		1		1				1		1		
	5				1 3		1 3		1						1 3		
	6				123		1 3		12						1 3		
	7				123		1 3		12						1 3		
	8																1
	9																
	10													2			
	11																
	12				1		1		1						1		
	13				1		1		1						1		
	14			2	12		1	12	12				12	12	12		
	15	1				1				1			12			1	
	16				1	1			1	1					1		
	17				12				12								1
	18				1		1			12					1		1
	19									1							
	20																
	21	1								1							
	22				1 3	1 3			1	1 3					1 3		
	23					3	1 3						1 3				3
	24			1 3		1 3	123	1 3		1 3			123			1 3	1 3
	25				1 3				1 3						1 3		1 3
	26													1			1
TASK COMMANDER	27																1
	28																1 3
	29						1 3						12				
	30				1				1						1		
	31																
	32				12								12				1
	33	1	1							1	1						
	34									1				1			
	35	1				1	12			1			12			1	1
	36									1							
	37																1
	38	1								1							
	39				1 3	1 3			1 3	1 3					1 3		
	40	1 3				1 3				1 3							1 3
	41																1
GUNNER	42	3				3				3							3
	43	3				3				3							3
	44																
	45																
	46	3								3							
LOADER	47																
	48																
	49																
	50																
	51																
	52																
	53																
	54																
	55																
	56																1
	57														1		
	58																

Table 3.4

FIST: Summary of Significant Depressions of Critical Abilities

	TASK NO.	FATIGUE						DIURNAL RHYTHM		LIGHT LEVEL				STRESS			
		V	H	NF	R	PS	O	NF	R	V	H	DP	O	M	R	PS	C
FIST CHIEF	1													1 3			
	2														1 3		1 3
	3				1												1
	4				1												1
	5				3		3		3				23		3		
	6				2				2								
	7						23			23			23				
	8						1 3			123			123				
	9						1 3						123				
	10	123		123			123	123		123			123		1 3	123	1 3
	11				123		1 3		1 3	123			123		1 3	123	
	12									123			123				
	13				1				1	12					1		
	14	123		123			123	123		123			123		1 3	123	1 3
	15	1 3		1 3				1 3		1 3					1 3	1 3	1 3
	16	1 3		1 3			1 3	1 3		1 3			1 3			1 3	1 3
	17														3		3
	18																3
	19				3				3						3		3
	20	123		123			123	123		123			123		1 3	123	123
	21	1		1				1		1						1	1
	22			123			123	123		123			123		1 3	123	123
	23	3		3			3	3		3			3		3	3	3
	24			2			2	2					2				2
	25			123	123			123	123						123		123
	26	123		123		123	1.3	123	123	123			123	123	123	123	123
	27									1				1		1	1
	28																
	29																123
FORWARD OBSERVER	30													1 3			
	31													123			
	32														1		1
	33														123		123
	34																
	35				1 3		123		1 3				123		123		
	36						23			23			23				
	37						1 3			123			123				
	38			123			1 3	1 3					123				
	39	1 3				1 3	1 3			123			123			123	
	40			123				123		123							
	41			123				123		123							
	42				123		1 3		1 3	123			123		1 3	123	
	43									123			123				
	44				23				23	23					23		
	45	123		123			123	123		123			123		1 3	123	1 3
	46	3		3				3		3					3	3	3
	47	1 3		1 3			1 3	1 3		1 3			1 3		1 3	1 3	1 3
	48	123		123			123	123		123			123		1 3	123	123
	49	1 3		1 3				1 3		1 3						1 3	1 3
	50			123			123	123		123			123		1 3	123	123
	51	3		3			3	3		3			3		3	3	3
	52			2			2	2					2				2
	53			123	123			123	123						123		123
	54	123		123		123	123	123	123	123			123	123	123	123	123
	55									1				1		1	1
	56																123
FIRE SUPPORT NCO	57													3			
	58																3
RADIO TELEPHONE OPERATOR	59													23			

Table 3.5

Artillery: Summary of Significant Depressions of Critical Abilities [1/]

TASK NO.	FATIGUE						DIURNAL RHYTHM		LIGHT LEVEL				STRESS			
	V	H	NF	R	PS	O	NF	R	V	H	DP	O	M	R	PS	C
1									LMH							
2			MH			MH	LMH		MH			MH	H			H
3						MH						MH				
4			LMH			MH	MH		H			MH	MH	MH		MH
5									H					MH		
6			H	MH									H	H		
7									H							
8									MH							
9	MH		MH			MH	MH		MH			LMH		MH		
10				H		MH			LMH			LMH				
11	MH						H		LMH					MH		
12														H		
13																H
14																H
15			LMH				LMH		LMH							MH
16	MH		LMH	MH			LMH		MH			MH				
17									MH			H		MH		MH
18	MH		MH				MH		LMH							
19			MH						MH							
20	MH		MH			MH			LMH			MH				
21	MH		MH													
22			LMH				MH		MH							
23			LMH				MH		MH							
24			LMH				MH									
25	MH								LMH			MH				
26	MH								MH			MH				
27	MH								MH							
28	MH								LMH			MH				
29	H								MH							
30	MH		MH				LMH		LMH							
31						LMH						LMH				
32						MH			LMH			LMH	MH			
33						MH			LMH			LMH	MH			
34			MH			MH	MH					LMH	MH			
35																
36																
37																
38																
39																
40		MH														MH
41									H							
42									MH							
43									MH						MH	
44																
45									H							
46																
47									MH							
48				MH									MH	MH		

[1/] In this table "L" denotes a significant depression with "Low" demand, "M" denotes the same for "Medium" demand, and "H" for "Heavy" demand.

Index of Effectiveness of Performance--E

Before continuing with the explanation of how data in these tables were used to arrive at a projection of performance degradation over 120 hours (5 days) of continuous operations, a measure or index of effectiveness is presented. Prior to the development of a mathematical model (or set of related equations), the groundrule was established that any index should be bounded zero and unity. These extremes would define, respectively, the absence and presence of effective combat performance.

With the stipulation that $0<E<1.00$, the question arose as to the meaning of these extremes. The prospective data for the model (Tables 3.2 - 3.5) clearly do not support an interpretation of total absence of any performance, as in the case of a fatality, nor of absolute perfection of task performance. However, these data justify an interpretation of $E=1.00$ as performance at a normal, routine level as, for example, at the very beginning of continuous combat operations, or in routine (recent) tactical exercises of the military unit of reference. Similarly, $E = 0$ can be interpreted as the degradation of performance to a level at which the unit of reference has ceased to have any further useful military significance. E is, therefore, not an absolute measure of performance but a relative one; it is an expression of "remaining" performance capability relative to (compared to) norms established by a given military unit (duty position, squad, platoon, etc., etc.), or of a generalized norm for an abstracted "standard" military unit of reference.

The Impact Vector

While the search through the scientific literature produced sufficient information to make well supported judgments as to the various impacts on abilities, the information was not adequate to support judgments as to interactions among debilitating factors, among critical abilities, or across both. Accordingly the model, called the Impact Vector Model, can consider only the data or values in Tables 3.2 through 3.5 whose derivation from empirical evidence has been outlined.

Given that the line of departure for the model would be the impacts (degree, quantity, intensity) on abilities, the function generated must be such as to intersect 0 and 1.00 respectively on the ordinate and abscissa of its plot. A third consideration was that the function should be an exponential one, because it has been found generally that such functions coincide well with patterns of empirical evidence. Further support for this assumed constraint is presented below in the discussion of the Progressive Degradation Function (PDF). Also, since the entire applicable set of abilities in question is considered critically requisite (absolutely essential) to task performance, a logical conjunction is implied, i.e., abilities a & b & . . . & $n \rightarrow P_i$ (performance of the i^{th} task). Such a joint consideration of the set of abilities in question is assured either by the arithmetic multiplication operator or by an exponential parameter.

Examination of Table 3.1 establishes that the maximum number of possible impacts on abilities for a hypothetical task requiring each and every critical ability equals 16. This represents a theoretical worst case, i.e., theoretical with respect to the formal premises. Also, this worst case distribution of depressant effects (impacts) is 1, 1, 2, 1, 2, 2, 2, 3, 2 as is evident from the bottom row in Table 3.1. Neither the total number nor the distribution of impacts in the worst theoretical case necessarily have a counterpart in actuality. By contrast, the best theoretical case and the best occurring case do coincide in there being a total absence of any impacts. In short, the best case (E = 1.00) is defined by an impact vector of length 16, $\Sigma 0$, and $\sigma = 0$, while the worst case (E = 0) is defined by $\Sigma 16$ and $\sigma = .6285$.

The general equation for the desired function for the IVM takes the form:

$$E = b^{q + \sigma - a} - c \qquad (3-1)$$

where:

E = the index of performance effectiveness

a = a constant ($a > 0$), determined to be 1.8078 for the present case

b = a decremental constant ($0 > b > 1$), chosen as .9

c = a constant ($c > 0$), determined to be .2098 for the present case

q = the number of adverse impacts

σ = the standard deviation.

Constants a and c are determined by the requirement for E = 0 when q = 16, and E = 1.00 when q = 0.

In equation 3-1, the standard deviation, σ, is defined in a standard way:

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^{n} (X_i - \overline{X})^2 \right]^{\frac{1}{2}} \qquad (3-2)$$

where:

n = the number of impacts in the vector

X_i = the i^{th} impact

$\overline{X}$ = the mean of the set of impacts

The Progressive Degradation Function

Formula 3-1, when applied to any task in Tables 3.2 through 3.5 and the corresponding vector of impacts, generates a value of E representing the joint and full impact of the applicable adverse or debilitating factors. While there is unanimity in the scientific literature that the full debilitating effects

of sleep loss take place between the 36th and the 48th hour of continuous wakefulness, the effect is aggravated with further sleep deprivation. Moreover, for some cognitive functioning, the effects begin to manifest themselves after as little as 24 hours without sleep. The value of E obtained through formula 3-1, then, corresponds (conservatively) to the state of the military unit of reference at the beginning of the 49th hour of continuous operations.

In order to obtain a function that would modify the calculated values of E so as to extrapolate them to 24, 72, 96, and 120 hours of sleep loss, the empirical evidence from the British study, "Early Call," (Haslam et al, 1977) described in Chapter I was examined. Available performance data of various types were amalgamated for each of the nine experimental (sleep deprivation) days of the study. Then, successively, a linear function, a power function, an exponential function, and logarithmic function were fitted to the data points according to a least squares criterion. Of these, the exponential function provided the best fit ($r = .977$). Therefore, an exponential form was chosen for the PDF.

This empirically derived function is:

(3 - 3)
$$E_i = E^{\frac{i}{2}}$$

where: E_i = the projected effectiveness of performance on the i^{th} day.

Compounding the Effectiveness Index (E)

It is evident that each value of E is calculated from a specific task impact vector, i.e., E pertains to the performance of one specific task. Since specific military tasks are normally performed by incumbents in particular duty positions (DPs), each of several sets of such tasks can be identified with one of various duty positions (see Tables 3.2 through 3.5). The effectiveness of a given duty position, then, will be equivalent to the value of E compounded across the corresponding set of tasks.

E for Platoon Actions

Analogously, E is calculated for a specific task occurring within one of the three types of defensive (platoon) actions. A compounding or averaging for the tasks within the three defensive types of actions is of interest when the type of defensive action is unspecified and only a general effectiveness projection is desired.

Because isolated, extremely deviant cases (i.e., of degraded task performance), should not unduly influence averages and in keeping with widely used equipment reliability estimation practice, the geometric mean was chosen as

the appropriate compounded index. Hence, the value of E over any given set of tasks or defensive (platoon) actions is calculated as follows:

$$\bar{E} = \left(\prod_{i=1}^{i=n} E_i\right)^{\frac{1}{n}} \qquad (3-4)$$

where:

$\bar{E}$ = the geometric mean or compounded value of the set of E_i

E_i = the value of E for the i^{th} task (or defensive action)

n = the number of values of E_i being considered.

Rules for Complex Compoundings

When formula 3-4 is applied to any given duty position, n equals the number of critical tasks performed by persons in that duty position. For example, from the critical task list appearing in the prior chapter, or from Table 3.2, the Gunner, Carrier Team Leader duty position of the mechanized infantry subsumes 17 critical tasks. Therefore, in calculating $\bar{E}_{DP}$ for this duty position:

$$\bar{E}_{G/CTL} = \left(\prod_{i=1}^{i=17} E_i\right)^{\frac{1}{17}}.$$

In calculating the compound effectiveness of more inclusive military units of reference, however, more complex rules are necessary. This necessity arises from the fact that certain duty positions occur several times within a higher order unit so that standard patterns must be established and defined. While a full strength infantry squad subsumes 11 men of various DPs, for present purposes an understrength squad consisting of one Squad Leader (SL), one Gunner, Carrier Team Leader (G/CTL), and four Maneuver Team Members (MTMs) was assumed. Thus, for example, $\bar{E}_{MTM}$ needs to be considered four times in calculating the compounded index for the entire squad ($\bar{E}_{Sq}$). In applying formula 3-4 to the mechanized infantry squad the following rule was observed:

$$\bar{E}_{Sq} = \left(\bar{E}_{SL}\, \bar{E}_{G/CTL}\, \bar{E}_{MTM}^{\,4}\right)^{1/3}.$$

Similarly, a mechanized infantry platoon consists of three squads headed by one Platoon Leader (PL), and the rule takes the form:

$$\bar{E}_{Plt} = \left(\bar{E}_{PL}\, \bar{E}_{Sq}^{\,3}\right)^{\frac{1}{4}}.$$

The higher level--general--rule being followed is to consider $\overline{E}_{DP}^{\frac{1}{n}}$ for multiples of DPs within the encompassing unit of reference (within brackets), but to reserve $\overline{E}^{\frac{1}{n}}$ for the number of types of values entering into the compounding (outside brackets). This general rule is in keeping with the considerations underlying the use of the geometric mean as the compounded index.

The specific applications of the rule to mechanized infantry units were presented in the preceding examples. For armor (tanks), the specific application of the rule was one PL and three tanks (TK) manned by one Commander (CDR), one Gunner (GR), and one Loader (LDR), or:

$$\overline{E}_{TK} = (\overline{E}_{CDR}\ \overline{E}_{GR}\ \overline{E}_{LDR})^{1/3}$$

and

$$\overline{E}_{TK\ Plt} = (\overline{E}_{PL}\ \overline{E}_{TK}^{1/3})^{\frac{1}{2}}$$

The assumption of an understrength condition governed throughout all units in correspondence with the established scenario. In the case of FIre Support Teams (FIST), the application of the general rule produced:

$$E_{TM} = (\overline{E}_{FO}\ E_{RTO})^{\frac{1}{2}}$$

and

$$E_{FIST} = (\overline{E}_{Chf}\ \overline{E}_{FS\ NCO}\ E_{TM}^{\frac{1}{2}})^{1/3}$$

Finally, in the case of artillery, the normal complement of six guns per battery was assumed to have been reduced to three, but each piece was regarded as fully manned. Thus, for artillery, the application of the rule was:

$$\overline{E}_{How} = (\overline{E}_{How\ SC}\ \overline{E}_{GR}\ \overline{E}_{CM}^{1/3})^{1/3}$$

and

$$\overline{E}_{Btry} = (\overline{E}_{XO}\ \overline{E}_{How}^{1/3})^{\frac{1}{2}} .$$

The various and extensive arrays of values calculated in accordance with the mathematical approaches described hereabove are voluminous. Therefore, they are not reproduced within the present report. All calculated projections are found in the companion Guidelines (Volume I of the set).

An Alternate Approach--Regression Analysis

An alternate approach to the Impact Vector Model (IVM) and Progressive Degradation Function (PDF), multiple linear regression, can be used to

develop these same projections. Initially the requirement for seemingly debatable assumptions and data transformations produced a hesitation to depend on this approach. However, comparisons of results obtained from both methods (IVM, PDF, and multiple regression) demonstrated an extremely high degree of agreement between them (over all comparisons, r = .979).

Table 3.6 presents sample data from the mechanized infantry representing duty positions, squads, and platoons under all combinations of adverse impacts. These values will be used to illustrate the regression approach. Five levels of severity representing mission duration (24 hours through 120 hours or one to five days) are distinguished in the case of Fatigue (F) or sleep loss as an impacting factor, whereas only two levels (0, 1) are distinguished in the case of Diurnal Rhythm (D), Stress (S), and Light Level (L). The impacting factors are arranged to be uncorrelated, i.e., non-overlapping. When this is the case, the optimal regression weight for any predictor variable (impacting adverse factor in the present application) remains unaffected by the weight developed for the other variables. Hence, the regression weight for each of four predictors can be chosen as if the dependent measures (E_{PL}, E_{SL}, . . . , E_{Plt}) are to be predicted from it alone. This procedure is justified by the theory of reduced variance regression (Darlington, 1978).

Although calculated profiles for a five day (120 hour) mission tended to be weakly quadratic in nature, a linear regression model was chosen for the predictive equations. Dawes and Corrigan (1974) have shown that linear models work well in practice and have cited reasons for these observations. Accordingly, the general form of the predictive equation is:

$$E_S = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \qquad (3-5)$$

where:

- E_S = the predicted performance effectiveness expressed as a percentage
- a = a constant
- $b_1, \ldots, b_4$ = the weights attached to the four predictors
- x_1 = Fatigue level
- x_2 = Light level
- x_3 = Stress level
- x_4 = phase of diurnal rhythm.

Zero order correlations between the factors and performance effectiveness may be used to assess the relative importance of impacting factors in debilitating the requisite abilities and, hence, degrading performance over the 120 mission hours (5 days).

Table 3.6

Summarized Effectiveness (E) of Mechanized Infantry: Duty Positions, Squads, and Platoons Under all Combinations of Adverse Conditions

Impacting Debilitating Factors				Duty Position				Infantry	
F	L	S	D	PL	SL	MTM	GR	Squad	Platoon
24	0	0	0	93	85	94	92	92	95
24	0	0	1	89	79	94	90	89	93
24	0	1	0	86	78	91	87	87	91
24	1	0	0	88	78	90	86	87	92
24	0	1	1	82	73	90	85	85	88
24	1	0	1	85	73	89	83	84	90
24	1	1	0	82	71	87	81	82	88
24	1	1	1	78	66	86	79	80	85
48	0	0	0	72	56	81	73	73	81
48	0	0	1	69	53	81	71	71	79
48	0	1	0	67	52	78	69	70	77
48	1	0	0	69	52	77	68	69	78
48	0	1	1	64	48	78	68	68	75
48	1	0	1	66	48	77	66	67	76
48	1	1	0	64	47	74	65	66	75
48	1	1	1	61	44	74	63	64	73
72	0	0	0	57	37	70	57	58	69
72	0	0	1	54	35	70	56	57	67
72	0	1	0	53	34	69	54	55	66
72	1	0	0	54	34	68	53	55	67
72	0	1	1	51	32	67	53	54	65
72	1	0	1	52	32	66	52	54	65
72	1	1	0	50	31	65	50	52	63
72	1	1	1	48	29	64	49	51	62
96	0	0	0	44	25	60	45	47	59
96	0	0	1	42	23	60	44	45	57
96	0	1	0	41	23	58	43	45	56
96	1	0	0	42	23	58	42	44	57
96	0	1	1	39	21	58	42	43	54
96	1	0	1	40	21	57	41	43	55
96	1	1	0	39	21	55	40	42	54
96	1	1	1	37	19	55	39	40	52
120	0	0	0	34	16	52	36	37	49
120	0	0	1	33	15	51	35	36	49
120	0	1	0	32	15	50	34	36	48
120	1	0	0	33	15	49	34	35	48
120	0	1	1	31	14	50	33	34	47
120	1	0	1	31	14	49	33	34	47
120	1	1	0	30	14	47	32	34	46
120	1	1	1	29	13	47	31	32	45

Table 3.7 indicates differences between correlation coefficients which reflect the relative importance of the impacting factors for different duty positions, squads, and platoons. For all units of reference, the model implies fatigue to be the most important factor in degrading performance. After the first two or three days of continuous operations, the other impacting factors are implied to play a small role and to contribute in a minor way to performance degradation. The regression model is designed so that fatigue carries a zero (0) weight during the first 24 hours of continuous operations, a one (1) for the next 24 hours, and so forth.

Table 3.7

Correlations Between Impacting Factors and Effectiveness for Different Infantry Positions, the Squad and the Platoon

Impacting Factor	Position				Infantry	
	PL	SI	MTM	G/CTL	Squad	Platoon
Fatigue	-98	-96	-99	-98	-98	-98
Light Level	-07	-08	-12	-11	-09	-08
Stress	-11	-08	-09	-08	-08	-10
Diurnal Rhythm	-06	-06	-02	-04	-05	-06

Note: Decimals are omitted from tabled entries.
PL = Platoon Leader
SL = Squad Leader
MTM = Maneuver Team Member
G/CTL = Gunner/Carrier Team Leader

Optimally weighted equations for predicting the percentage of remaining effectiveness (E x 100) for the Platoon Leader (PL), Squad Leader (SL), Gunner/Carrier Team Leader (G/CTL), Maneuver Team Member (MTM), Squad (sq), and Platoon (Plt) are presented below. Since the six multiple correlations ranged between R = .97 and R = .99, the linear fit is good.

$$\overline{E}_{PL} = 100 - 13.4X_1 - 2.75X_2 - 4.15X_3 - 2.45X_4$$

$$\overline{E}_{SL} = 88.7 - 15.0X_1 - 3.45X_2 - 3.45X_3 - 2.75X_4$$

$$\overline{E}_{MTM} = 102 - 10.1X_1 - 3.40X_2 - 2.50X_3 - 0.50X_4$$

$$\overline{E}_{G/CTL} = 99.4 - 13.0X_1 - 4.00X_2 - 3.00X_3 - 1.40X_4$$

$$E_{Sq} = 99.5 - 12.7X_1 - 3.35X_2 - 2.85X_3 - 1.75X_4$$

$$E_{Plt} = 103 - 10.7X_1 - 2.35X_2 - 3.15X_3 - 1.75X_4$$

While the least squares regression model captured most of the variance in the performance measure produced by the IVM, other models might also be considered. One alternative is to replace the coefficients developed through the multiple regression technique with equal weights. Probably very little loss in accuracy with respect to the original sample data would result from this procedure. There are at least three reasons for considering equal weighting: (1) the weighting issue is subsidiary to specifying the relevant impacting factors (variables) for the model, which is primary; (2) while sampling error is present in estimating regression weights, equal weights have no sampling error; and (3) simulation techniques (Schmidt, 1971; Claudy, 1972) have shown that equal weighting schemes perform quite well when compared with optimal (least squares) regression weights. The model with equal weights can be expected to be very robust for the general case, giving only a slightly lower correlation with the operational criterion than the least squares estimates of the regression coefficients (Einhorn & Hogarth, 1975; Wainer, 1976).

Whichever version of the regression approach is used--least squares or equal weights--the approach provides an alternative to the IVM and PDF approach. Certainly either approach projects much the same picture of degradation, and that picture is highly congruent with literature summaries (e.g., with respect to sleep loss, Woodward & Nelson, 1974) and with specific empirical studies (e.g., Haslam et al, 1977).

The close agreement between the results obtained when using the IVM/PDF model and the regression model provides support for the detailed decrement data presented in the Guidelines. Two different approaches agree closely and, accordingly, evidence on convergent validity is on hand.

CHAPTER IV

SIMULATION MODEL

During the course of the present work, it became apparent that no computer simulation model is available for simulating the effects of continuous operations on performance effectiveness. Such a model is required if performance degradation effects are to be considered against the backdrop of such factors as varying light level, terrain advantage, enemy/friendly strength ratio, and the like. This chapter presents a simulation model which was designed to simulate such effects in interaction with the performance degradation due to the effects of continuous operations. The psychological condition of the troops is a primary variable in the model. This variable is reflected in a representation called "stress."

The model is named "PERFECT" for PERFormance Effectiveness of Combat Troops, since its objective is to process the detailed effectiveness data presented in the Guidelines and to produce summarized effectiveness predictive curves for specified numbers and types of Army combat units during continuous operations. The approach permits an analyst to make computer runs under input parametric conditions which he selects, and to observe the effect of these conditions on the general effectiveness levels of the combat units involved. The model permits continuous operations to be simulated over five day periods. It is highly flexible and is designed to run from a small scale computer system terminal. For most applications, minimum input requirements are involved. Use of the model requires little, if any, knowledge of computer systems. Moreover, the model is designed to run quickly and to provide output on line. This facilitates the performance of interactive "experiments" in which a set of "what if" questions may be answered.

Model Overview

The model as described here represents the concepts and specifications as they were developed at the initiation of computer programming of the model. Following completion of programming and testing of the model, it is planned to document a more current and detailed description of the model. The results of a series of planned sensitivity test runs will also be reported at that time.

A list of some of the major features of the PERFECT model is shown in Table 4. 1. The simulation model is based on a series of manipulations of a four dimensional effectiveness matrix as a function of the composition of the combat force, the mission (platoon action) sequence designated, and parameter input values. In general, effectiveness levels will degrade as a function of time but improve (increase) with sleep/rest (if sleep/rest is specified by the parameter inputs). Effectiveness also degrades with increasing

stress level of the troops. This level, in turn, is a function of light level conditions, terrain advantage, squad proficiency level, enemy/friendly personnel strength ratio, friendly vulnerability, and enemy/friendly material strength ratio. Effectiveness also improves (i.e., is restored) when platooning is specified to replace designated combat units.

Table 4.1

Summary of Features of Simulation Model

- Utilizes squad level effectiveness values presented in Guidelines document
- Incorporates stress build up via battle conditions and stress relief via sleep
- Flexible, understandable set of input parameters
- Programmable for computer terminal and graphic output options
- Accomodates continuous operations durations up to five days
- Optional platooning (replacement) at the squad level
- Extendable to offensive operations
- Variety of output options selectable
- Output of effectiveness profile by combat unit type and by performance factor

In order to gain a perspective of the scope or "size" of the model, it is helpful to observe the current values selected for the maximum value of key variables. These are shown in Table 4.2. The model will initially handle operations up to five days in length. It will consider a maximum of 16 duty positions and nine unit types (mechanized infantry, armor, etc.). The PERFECT model will simulate the three platoon actions described in the Guidelines on the basis of five summary factors. The model is designed so that these limits can be expanded later, if desired, to simulate offensive, reconnaissance, and retrograde operations and additional duty positions, combat unit types, factors, and platoon actions.

Table 4.2

Principal Model Limits

Variable	Maximum Current Value
Days	5
Duty Positions	16
Type of Combat Unit	9
Number of Units of Each Type	5
Factors	5
Platoon Actions	3

It is expected that the resultant model will allow an analyst, using a computer terminal, to enter parameters, make any input data changes necessary, implement a simulation run, and receive a report and plot of results within a reasonable response time. This capability will make practical a series of runs in which the selection of a subsequent run can be dependent on the results of prior runs.

Three types of input data--parameters, mission data, and data arrays--are required for the model. These are shown in Table 4.3.

Parameters

The series of input parameters listed in Table 4.3 was selected to make the model flexible, i.e., capable of simulating a wide range of interesting continuous operations situations. These input parameters were also selected so as to require no data collection or analysis by the user when he performs simulation runs.

Mission Data

The mission data represent the sequential list of platoon actions and corresponding durations for each unit type to be simulated over the continuous operation. Up to five units of each of nine types can be specified in a run which simulates up to five days of continuous operation.

Arrays

Input data arrays are those matrices required as a basis for the model's calculations.

Table 4.3

Input Data Summary

Parameters	Data Requirement Code*
Proficiency/speed factor by unit type, UPF (ITYPE)	S
Enemy/friendly material strength ratio, EFM	S
Enemy/friendly personnel strength ratio, EFP	S
Enemy/friendly terrain advantage for each day, EFTA	S
Light level profile code (1 of 9) for each day, L (IDAY)	S
Unit replacement conditions	S
Time of day that battle starts, HR	S
Output recording options, OUT	S
Hours since last sleep at battle start, HSLS	S
Preprocessing indicator, PRE	B
Mission Data	
Platoon action and duration for each combat unit, each day, PA (U, T), DUR (U, T)	S
Data Arrays	
1. Factor numbers for each critical task by combat unit type, FAC	P
2. Effectiveness by platoon action, duty position, critical task, and day, EFF (PA, DP, CT, D)	P
3. Manning table, i.e., number of troops of each duty position by unit type, MEN (IDP)	P
4. Light level value for each of nine type of day situations, LIGHT (H, L)	P

* Data Requirement Code:

S – for simulation

P - for preprocessing

B - for both

Three of the four data arrays are stable and require no operator action. Data array 1, factor assignment for each critical task, is given in Appendix I to this chapter. Table 4.4 shows the assignment of each of the five factors.

The original factor derivation was based on a factor analysis of the various tasks. This factor analysis is described in Appendix II to this chapter.

Table 4.4

Factors and Factor Task Assignment Values

Factor Number (F)	Factor
1	Command and Control
2	Combat Activity
3	Coordination and Information Processing
4	Preservation of Forces and Regrouping Activity
5	Orientation to Friendly and Enemy Troops

The effectiveness matrix (data array 2) is a detailed list of projected effectiveness values for critical combat tasks given in the companion Guidelines and whose method of derivation is described in Chapter III of the present volume. The matrix consists of detailed effectiveness values by unit type and duty position for each critical task over a five day continuous operation.

The assumption is that all effectiveness values are equal to one (no degradation) at the start of the battle. This is illustrated in Figure 4.1 for the mechanized infantry unit, maneuver team member, critical task 1, and platoon action 1. Data for a sixth mission day are calculated by linear extrapolation. This extrapolation is required due to the technique selected for stress calculation.

The manning table (data array 3) is shown in Table 4.5. Table 4.5 also shows the assignment of the nine unit types and the 16 duty positions. The input values of the manning table, i.e., the number of men in each duty position per unit type to be simulated is shown as the next to the last column of Table 4.5. If these data are not entered for a given run, then the default values listed in the default column will be used by the model.

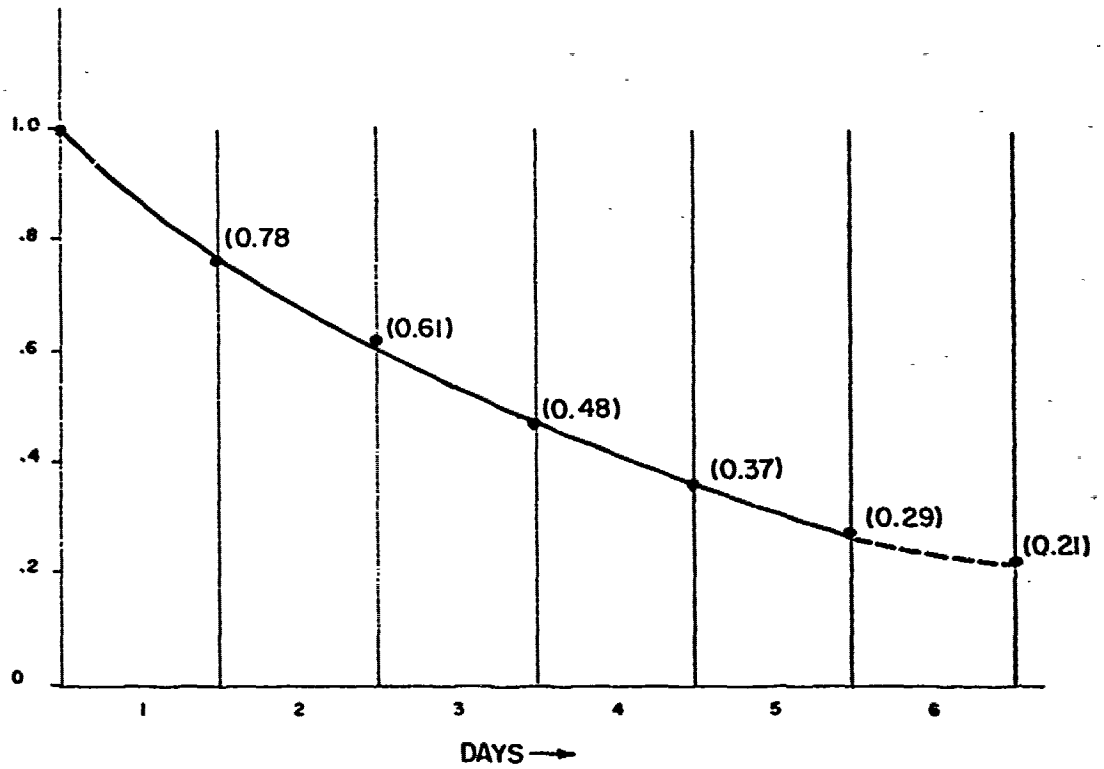


Figure 4.1. Example of "Effectiveness" curves (linear approximations are used in the model.)

Light level input data and conditions are shown in Table 4.6. One light level profile number (1 - 9) is selected as input for each day of the simulated mission. The light level profile input parameters identify one of the nine preselected 24 hour sets of light conditions shown in Table 4.6(a). Each value selected represents a type of day (weather) to be simulated. The individual values in Table 4.6(a) represent hourly light level conditions whose meanings are shown in Table 4.6. Table 4.6 is data input array 4.

Platoon action code assignments are shown in Table 4.7. Initially, only the codes for sleep (0) and the platoon actions described in the companion Guidelines (platoon action 1 = repel on enemy assault from a battle position, platoon action 2 = create and defend a strong point, platoon action 3 = disengage and occupy a new battle position) are utilized. The program is written so as to provide for expansion of the number of platoon action types with relative ease in the future. This will allow later simulation of offensive and other operations either individually or together with the currently available platoon actions.

Other Input

Other required input to a simulation run are platoon action code assignment and enemy/friendly terrain advantages.

Table 4.8 was prepared to facilitate selecting the enemy/friendly terrain advantage input value. Three elements were identified as significant in terrain advantage: concealment, altitude advantage, and mobility. They are assumed to have equal importance. Table 4.8 shows various conditions of enemy, friendly, or no advantage and a corresponding value of the input parameter which can be selected to represent each of the cases. The values of enemy/friendly terrain advantage are used as multiplicative factors. The range was selected so that there is a five to one swing from the equilibrium condition to the case in which either side has complete advantage.

Model Processing Overview

Figure 4.2 presents a global view of the processing sequence. Note that the total program includes a preprocessor calculation. Any given run of the program can be a preprocessor only run (PPO), or a simulation only run (SIM), or a preprocessor run plus a simulation (PPS). This reduces simulation time since the preprocessor portion need not be recalculated on all runs. Table 4.3 also shows (for each input data category) which data types are required for a preprocessor run, for each simulation run, or for a combined run.

Table 4.5

Manning Table Input

Unit Type Identifier (I TYPE)	Unit Type	Duty Position		No. of Men		No. of Critical Tasks ICT (DP)
		Number IDP	Name	Default Value	Number MEN (IDP)	
1	Mechanized Infantry Squad	1	Gunner/Carrier Team Leader	1		17
		2	Maneuver Team Member	4		15
		3	Squad Leader	1		17
2	Mechanized Infantry Platoon Leadership	4	Platoon Leader	1		27
3	Tank Crew or Armor Crew	5	Tank Commander	1		15
		6	Tank Gunner	1		5
		7	Tank Loader	1		12
4	Tank Platoon Leadership	8	Tank Platoon Leader	1		26
5	Tank Crew Alternate	6	Tank Gunner	1		5
		7	Tank Loader	1		12
6	Fire Support Team (FIST)	9	Forward Observer	1		27
		10	Radio/Telephone Operator	1		1
7	FIRE Support Team Leadership	11	FIST Chief	1		29
		12	FIST NCO	1		2
8	Artillery Section	13	Howitzer Section Chief	1		11
		14	155 mm Gunner	1		17
		15	155 mm Crew Member	3		14
9	Artillery Battery Leadership	16	Artillery Battery Executive Officer	1		6

Table 4.6

Light Level Information - Array 4

Value of Light Level	Light Conditions
1	Starlight on earth
2	Starlight on snow or half moon
3	Full moon on earth
4	Full moon on snow
5	Late twilight
6	Early twilight/dense clouds or haze
7	Overcast day/light haze
8	Light, overcast day
9	Clear, sunny day

Table 4.6 (a)

Light Level Information - Array 4

Light Level Profile Number	Season	Type of Day	Value of Light Level at Each Hour * 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Winter	Hazy, overcast, no moon	1	1	1	1	1	3	5	7	7	7	7	7	7	7	7	7	5	3	1	1	1	1	1	1
2	Winter	Clear, no snow, full moon	3	3	3	3	3	4	6	9	9	9	9	9	9	9	9	9	6	4	3	3	3	3	3	3
3	Winter	Clear, snow, no moon	2	2	2	2	2	3	6	9	9	9	9	9	9	9	9	9	6	3	2	2	2	2	2	2
4	Winter	Clear, snow, full moon	4	4	4	4	4	5	7	9	9	9	9	9	9	9	9	9	7	5	4	4	4	4	4	4
5	Spring/ Fall	Clear, hazy, half moon	2	2	2	2	2	3	5	7	8	8	8	8	8	8	8	8	8	6	4	3	2	2	2	2
6	Spring/ Fall	Clear, half moon	2	2	2	2	3	4	6	8	9	9	9	9	9	9	9	9	9	8	6	4	3	2	2	2
7	Spring/ Fall	Rain, overcast, no moon	1	1	1	1	2	4	6	7	7	7	7	7	7	7	7	7	7	6	4	2	1	1	1	1
8	Summer	Fair, half moon	2	2	2	3	5	9	9	9	9	9	9	9	9	9	9	9	9	9	6	5	2	2	2	2
9	Summer	Rain, overcast, no moon	1	1	1	2	4	7	7	7	7	7	7	7	7	7	7	7	7	7	5	2	1	1	1	1

*Represents clock time of 0100 (i.e., 1:00 AM)

Table 4.7

Platoon Action Code Assignments

Platoon Action Number (PA)	Description	Platoon Action Type
0	Sleep	Sleep
1	Repel an enemy assault from a battle position	Active defense
2	Create and defend a strong point	
3	Disengage and occupy a new battle position	
4		
5	To be determined	Offensive Operations
6		
7	Reconnaissance	Reconnaissance
8	Retrograde	Retrograde
9	To be determined	To be determined

Table 4.8

Terrain Advantage Parameter Selection Guide

Enemy/Friendly Terrain Advantage Parameter Value (EFTA)	Number of Elements		
	Enemy Advantage	Equal	Friendly Advantage
0.2	All 3	-	-
0.4	Any 2	1	-
0.6	Any 2	-	1
0.8	Any 1	2	-
1.0	-	All 3	-
1.0	Any 1	Any 1	Any 1
1.25	-	Any 2	Any 1
1.667	Any 1	-	Any 2
2.5	-	Any 1	Any 2
5.0	-	-	All 3

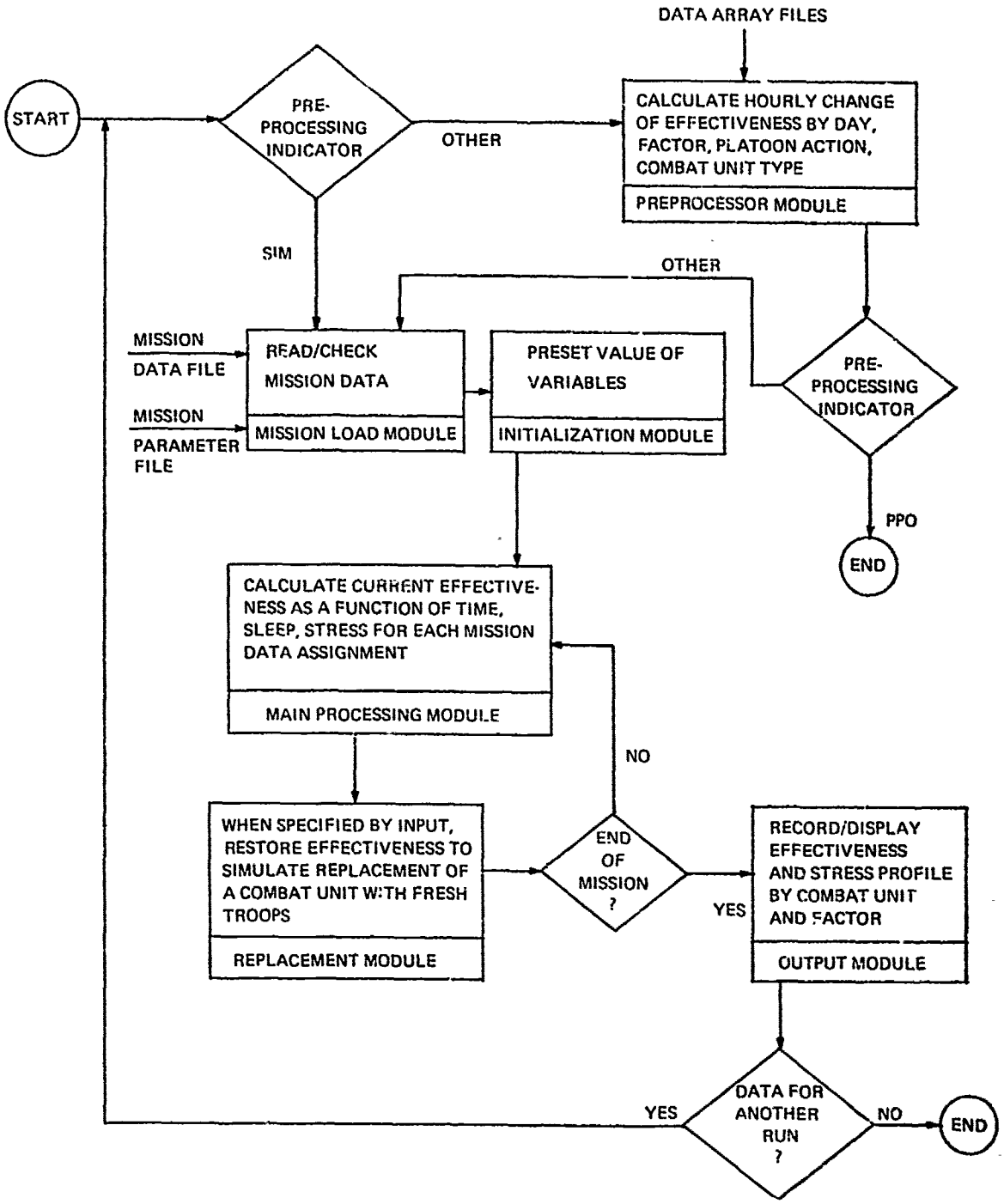


Figure 4.2. Overview of model flow logic.

The Figure 4.2 flow chart also shows the principal modules of the model and the primary functions of each. A detailed flow logic chart of the model is included as Appendix III.

The Preprocessor Module

The preprocessor module completes four major stages. These stages provide the basic data for the main simulation processing and reduces the calculational complexity during that stage. Prior to these four steps of arithmetic processing, the preprocessor allows interactively for changes to be made in the data arrays. This is accomplished via a menued sequence of choices and questions presented by the preprocessor. Reasonableness checks for inputs are also made.

Starting with the effectiveness matrix, the values for the end of each day (IDAY) for each platoon action (PA), duty position (IDP), and critical task (ICT), a smaller matrix is computed whose elements are the geometric mean of the effectiveness values for each of the five factors. The result is a matrix E2 (IDAY, PA, IDP, FAC) of the form:

	IDP = 1				IDP = 16		
Factor (FAC)	PA 1 IDAY = 1 - 5	. . .	PA 3 IDAY = 1 - 5	. . .	PA 1 IDAY = 1 - 5	. . .	PA 3 IDAY = 1 - 5
1							
2							
3							
4							
5							

In stage 2, the manning input data (array 3) are applied to the matrix resulting from stage 1 and another matrix E3 (IDAY, PA, FAC, ITYPE) is calculated by averaging over all duty positions according to the equation:

$$\frac{MEN(IDP) \cdot E2(IDAY, PA, IDP, FAC)}{\sum_{T} MEN(IDP, ITYPE)} \longrightarrow E3(IDAP, PA, FAC, ITYPE)$$

The resultant E3 (IDAY, PA, FAC, ITYPE) matrix has the following form:

Factor (FAC)	Unit Type 1				Unit Type 9		
	PA 1 IDAY = 1 - 5	. . .	PA 3 IDAY = 1 - 5	. . .	PA 1 IDAY = 1 - 5	. . .	PA 3 IDAY = 1 - 5
1							
2							
3							
4							
5							

The third stage is the translation of matrix E3 (IDAY, PA, FAC, ITYPE) into E4 (IDAY, PA, FAC, ITYPE) in which each element represents unit degradation in effectiveness per hour for all values of IDAY, PA, FAC, and ITYPE as follows:

$$E4\ (IDAY, PA, FAC, ITYPE) = \frac{E3\ (IDAY-1, PA, FAC, ITYPE) - E3\ (IDAY, PA, FAC, ITYPE)}{24}$$

Both matrices E3 and E4 have the same format, yet E3 contains values of effectiveness and E4 contains values of decreases in effectiveness per hour. During the fourth and last stage of the preprocessing the data for day 6 are added to the E4 (IDAY, PA, FAC, ITYPE) matrix by linear extrapolation. Although the simulation is limited to five days, data for day six are required to simulate conditions of stress on day five.

Note that preprocessing is required only when the manning table is altered since is not expected that values of the original effectiveness table or the factor table will change.

The mission load module consists of an extensive set of menued alternatives which allows the analyst to identify parameter values in response to simplified requests. Input values are verified for reasonableness.

Main Processing Module

The main processing module is generally repetitive in its processing, proceeding sequentially through the operation in time from the start to the end of the data. The processing generally follows the same sequence for each unit

in turn. The processing is based on the effectiveness data from the E4 matrix and is recycled for each of the following sequential quartets of information from the mission input:

Mission Data Element	Element Symbolics
Unit Type	ITYPE = 1 of 9
Unit Number of This Type	U = 1 of 9
Platoon Action Number	PA (D, U, T) = 0 to 9
Duration (hours) of the Platoon Action	DUR (IDAY, U, ITYPE) = 0 to 24

The mission input data consist of sets of these quartets representing 24 hour days (except the last day). Accordingly, the operation may be initiated at any time of day or night (by parameter) and its duration specified by mission data inputs. During the processing, the program calculates and keeps track of the following variables for each such quartet:

- current value of effectiveness
- current value of time (days and hours)
- current value of the stress factor
- a value of time change corresponding to that stress condition, called "stress time"
- length of time since last sleep

Current Value of Effectiveness

The current value of effectiveness is calculated as:

$$ECUR(IDAY,FAC,U,ITYPL) = ECUR(IDAY,FAC,U,ITYPE) - [E4(SD,PA,FAC,ITYPE)][STIME(U,ITYPE)]$$

This indicates that the value of current effectiveness equals the prior value less the product of the effectiveness degradation per hour for the current stress day and the value of stress time. (See Appendix III).

Current Value of Time

The current value of time for the unit under consideration is obtained by adding the current platoon action duration to a running total of the unit's prior time preset to zero at the start of the continuous operation simulation. Length of time since last sleep is handled similarly, but preset at the start of the action to the value of the "hours since sleep" parameter.

Current Value of Stress

The current value of the stress factor depends on the parameters: light factor (LIGHTF), enemy/friendly personnel strength ration (EFP), enemy/friendly material strength ration, (EFM), enemy/friendly terrain advantage (EFTA), proficiency/speed factor of the combat unit (UPF), and a variable called "vulnerability" which is represented by (1 - Efficiency):

STRESSF(U,ITYPE) = [EFM·EFP·LIGHTF(IDAY)·UPF(ITYPE)·EFTA][1 - ECUR(IDAY,FAC,U,ITYPE)]

When this stress factor exceeds the nominal value (selected as unity) the model takes account of this by effectively jumping the time ahead for the affected combat unit to simulate troops having a lower efficiency value. The amount of this jump is a function of the magnitude of the stress factor. It varies linearly from a value of zero (for stress factor equal to one) up to a maximum jump of 24 hours if the stress factor has a value of five or more. The value of this pseudo time variable is called "stress time" and the result is poorer (lower) effectiveness as a result of stress.

If a combat unit is scheduled for rest or sleep (i.e., if input PA data = 0 for a combat unit), then the processing includes the calculation of the following additional variables:

- hours of sleep deprivation, SLPDEP (U, T)
- number of hours sleep required for 100% recovery from sleep deprivation, $RECOVH = \frac{1}{0.03494} \ln \frac{SLPDEP(U, T)}{4.6949}$
- percentage recovery time of this sleep, $PERREC = \frac{DUR(U, T)}{RECOVH}$
- percentage of normal function recovered by this sleep,

$$PERNORM = (PERREC)^{0.5}$$

- number of effective hours decrease in stress time as a result of this sleep, EFFECT = (PERNORM)(SLPDEP(U, T))

End of Day Effectiveness

Several data sets result from these calculations but the primary one is the matrix E5 (FAC, IDAY, IUNNO, ITYPE) whose elements are end of day effectiveness values for each day, factor, unit type, and unit. It is helpful to conceptualize this matrix as being of the following form:

Factor (FAC)	Combat Unit Type 1				Combat Unit Type 9		
	IUNNO 1 IDAY 1-5	. . .	Last U IDAY 1-5	. . .	IUNNO 1 IDAY 1-5	. . .	Last U IDAY 1-5
1							
2							
3							
4							
5							

Personnel Replacement

The replacement module is entered whenever, during the main processing module calculations, a condition is reached corresponding to a specified unit, unit type, day, and time when the analyst has specified replacement of that unit in the original parameter input data. Entry into this matrix allows appropriate adjustment of variables to represent the replacement (platooning) of the selected unit by a fresh one, i.e., one for whom conditions (sleep deprivation, effectiveness, etc.) are the same as for the simulated personnel at the start of the operation. The model presently allows up to 20 such unit replacements during simulated continuous operations.

Output

The output module operates on the E5 (FAC, IDAY, IUNNO, ITYPE) matrix after all mission data have been completely processed by the main processing module. Its principle operations are averaging E5 (F, D, U, T) matrix values and providing either for listing these data on a line printer or possibly plotting them. First, end of day effectiveness values are averaged over all units of a given type. This yields a matrix E6 (D, F, T) of the following form:

Factor (FAC)	Unit Type 1		Unit Type 9
	IDAY 1 . . . 5	. . .	IDAY 1 . . . 5
1			
2			
3			
4			
5			

Using the E6 (IDAY, FAC, ITYPE) matrix, the model generates two additional but smaller tables for listing/plotting. These are E7 (IDAY, FAC) and E8 (IDAY, ITYPE) which show end of day effectiveness values by factors and by combat unit type respectively. Figure 4.3 shows the matrix formats and an idealized plot of these results.

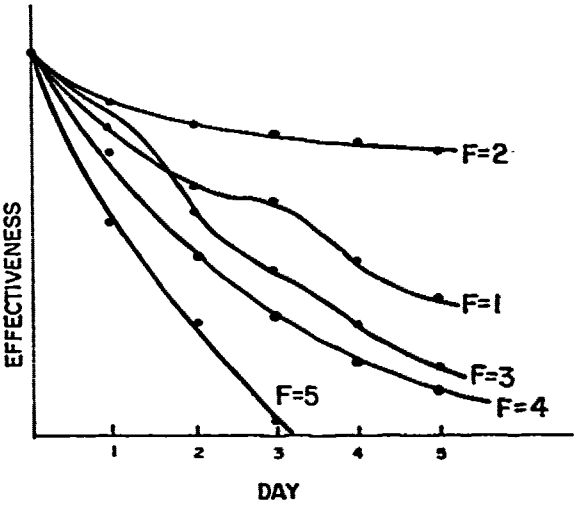
Also reported as output are maximum values of the stress factor as they occur during the simulation. The maximums are retained in storage for each unit type and are available in listed table form by the day after each simulation run. The output table contains the following information about the stress factor peak values: unit type number, day number, stress factor value, time of day, and unit number.

Summary

The PERFECT model is expected to allow an analyst to make interactive analyses of battle conditions as described. While operating at a computer terminal or via the means of batch run requests, the analyst will have at his disposal a number of key parameters for which he will be able to select values for each simulation run request. He will then have at his disposal a display of effectiveness and stress profiles which are predicted to result from the input conditions over the simulated battle.

E7 (D,T)

FACTOR	DAY			
	1	2 • • •		5
1 • • • 5	• • •		• • •	



E8 (D,T)

DAY	TYPE OF COMBAT UNIT, T		
	1		9
1 • • • 5		• • •	

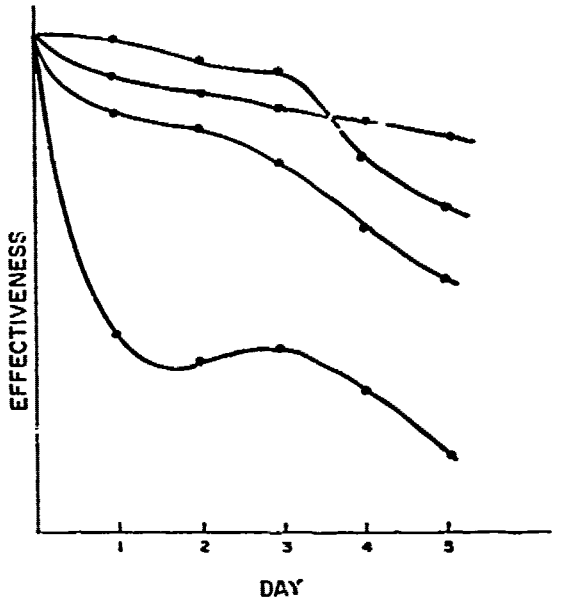


Figure 4.3. Idealized model output

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APPENDIX I

FACTOR TABLE INPUT

APPENDIX I

FACTOR TABLE INPUT
(INPUT DATA ARRAY I)

Critical Task No. (CT)	DUTY POSITION (IDP)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	2	2	2	4	3	4	2	3	3	3	2	3	4	5	3	1
2	2	2	1	2	3	4	2	3	3		2	3	2	5	3	1
3	2	2	2	3	5	3	2	5	1		2		5	5	3	1
4	2	1	4	4	5	2	2	5	1		2		4	5	5	1
5	2	1	1	1	1	2	5	5	1		5		4	5	3	2
6	3	4	1	3	3		5	5	5		2		4	5	1	1
7	5	2	1	1	4		5	5	4		4		1	5	3	
8	3	1	1	4	3		2	3	5		5		1	5	2	
9	2	2	1	4	5		2	3	5		5		1	5	2	
10	1	5	3	1	4		1	5	1		1		5	5	5	
11	2	2	1	2	3		2	5	4		1		1	5	5	
12	1	2	1	1	2		2	5	4		5			5	3	
13	4	2	1	3	5			5	1		1			5	5	
14	4	2	1	1	3			1	2		1			5	5	
15	5	2	1	1	3			4	1		1			2		
16	4		2	3				5	1		1			2		
17	3		1	4				5	1		2			5		
18				3				1	1		2					
19				1				4	1		2					
20				1				2	1		1					
21				3				2	1		1					
22				1				5	1		1					
23				1				1	1		1					
24				1				5	1		2					
25				1				1	1		1					
26				3				5	1		1					
27				1					3		1					
28											1					
29											3					
30																
31																
32																
33																

APPENDIX II

DERIVATION OF FACTORS

Derivation of Factors

The PERFECT model consolidates effectiveness in accordance with five combat activity oriented factors. This appendix describes the methods and procedures employed to derive these factors.

By way of overview, the factors were derived from five separate factors analyses of the critical tasks performed by mechanized infantry, armor, artillery, and FIST units. The results of the four factor analyses were integrated to yield five factors which are descriptive of the critical tasks performed by each of the four unit types.

Critical Tasks and Critical Abilities

Volume I of this set (the Guidelines) identified the critical tasks performed by each of the four unit types during the conduct of an active defense. Table II. 1 summarizes the number of critical tasks by arms team unit type and position.

Volume I also listed and defined the perceptual-motor, mental, and social interactive abilities considered in the context of the present work to affect human performance during continuous operations. Table II. 2 lists and defines these abilities.

Basis for Factor Analysis

Two human factors experts, who are familiar with the continuous operations concept, were given the four task lists and the set of 15 abilities. Each expert was instructed to judge independently which abilities were essential to perform each task in each list.

After making their independent judgments, the two experts met and resolved differences. The result was four matrices (one matrix for each type of unit) representing the involvement or noninvolvement of each ability in each task.

Factor Analysis

Each matrix was separately factor analyzed using the PA 1 option offered in the Statistical Package for Social Sciences. The analysis made it possible to separate the common variance of the tasks in each matrix into a minimum number of uncorrelated portions representing the underlying factors. For each unrotated factor matrix, rotation to orthogonal simple structure was performed in accordance with the varimax criterion. For rotation, the number of factors was set at a minimum eigenvalue of 1.00.

Table II-1

Number of Critical Tasks by Unit Type/Position

Unit Type Position		Number of Critical Tasks
Mechanized Infantry	(Total)	76
Platoon Leader		27
Squad Leader		17
Maneuver Team Member		15
Carrier TM LDR/Weapons Operator		17
Vehicle Driver		0
Tank Platoon	(Total)	58
Tank Platoon Leader		26
Tank Commander		15
Tank Gunner		5
Tank Loader		12
Tank Driver		0
FIST	(Total)	59
FIST Chief		29
Forward Observer		27
Fire Support NCO		2
Radio Telephone Operator		1
Artillery Battery	(Total)	48
Battery Executive Officer		6
Howitzer Section Chief		11
Gunner		17
Crew Member		14

Table II.2

Definition of Each Ability Considered During Present Work

Perceptual-Motor Abilities

1. Vision--the ability to detect visually objects and relations among objects such as movement or relative distances
2. Hearing--the ability to detect significant sounds amid competing sounds
3. Strength--the ability to move objects using the body and limbs
4. Impulsion--the ability to react quickly to light and sound by making rapid movements such as running and jumping
5. Motor Speed--the ability to maintain a high personal tempo and perform accurately using arms, hands, and fingers
6. Static Precision--the ability to maintain good body balance and arm steadiness while aiming
7. Dynamic Precision--the ability to maintain body balance and make accurate aiming movements while the body is in motion

Mental Abilities

8. Numerical Facility--the ability to add, subtract, multiply, and divide (including when they are part of other operations such as finding percentages)
9. Verbal Facility--the ability to use and understand the written and spoken language
10. Memory--the ability to remember information such as words, sounds, pictures, and procedures
11. Orientation--the ability to orient in three-dimensional space
12. Reasoning--the ability to apply rules to problems and to come up with answers or decisions or to combine pieces of information to form a rule or to produce a set of rules necessary to arrange things or actions in an order
13. Perceptual Speed--the ability to compare letters, numbers, objects, pictures, or patterns, present or remembered, both quickly and accurately

Table II.2 (Cont.)

Definitions of Each Ability Considered During Present Work

Social Abilities

14. Social Coordination--the ability to coordinate activities with one or more members of a group or to give direction or orientation to one or more members of a group

15. Communication--the ability to transfer required and/or relevant information in proper depth and scope at the proper time.

A five factor solution emerged for each of the four analyses. Several of the factors in the solutions containing more than five factors had so few tasks highly loaded on them as to be uninterpretable.

Mechanized Infantry Solution

For the mechanized infantry, a five factor solution cumulatively accounted for 84.9% of the unrotated variance. The final rotated factor loadings are presented as Table II.3. The factors were named: Command and Control Activity, Combat Activity, Coordination and Information Processing, Preservation of Forces and Regrouping Activity, and Orientation to Friendly and Enemy Forces. A sample of the tasks loading highly on each factor is presented below in support of the factor names selected.

I. Command and Control Activity

(12) Direct relocation or repositioning
(21) Plan and fire effective positions
(22) Coordinate weapon's locations
(34) Establish communication network
(37) Establish routes to subsequent positions
(41) Direct relocation fire
(43) Direct move to assembly area
(54) Direct mounted defense
(59) Assign locations to SLs
(61) Assign fire zones and targets

II. Combat Activity

(1) Fire from bounding vehicle
(2) Overwatch bounding vehicle
(3) Fire to protect bounding vehicle
(18) Check condition of weapons
(24) Identify TRP's
(26) Fire on targets
(28) Fire with NVD's
(29) Move rapidly to new positions via marked routes
(33) Observe terrain for enemy presence

Table II.3

Loading of Each Task on Each Factor--Mechanized Infantry

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
01	-0.18173	0.82797	0.02421	0.15072	-0.14025
02	0.15745	0.96017	-0.04099	-0.04292	0.13546
03	-0.18502	0.79276	0.02363	0.15214	-0.06384
04	0.00751	0.91122	0.05719	0.18376	-0.17748
05	-0.45163	0.12297	-0.06704	0.02430	-0.02498
06	0.48490	0.44015	0.48424	-0.44908	-0.27889
07	0.34007	0.37673	-0.23657	-0.12702	0.79906
08	0.17583	0.00045	0.95824	0.05017	-0.03614
09	0.00751	0.91122	0.05719	0.18376	-0.17748
10	0.58115	-0.38077	-0.40921	0.31254	-0.33957
11	0.61474	0.60198	-0.36683	0.21003	-0.14426
12	0.59841	0.15266	0.49624	-0.05355	-0.08471
13	0.46025	0.17697	0.46305	0.71607	-0.00261
14	0.25489	0.59526	-0.19480	0.66115	-0.26133
15	0.53627	0.0378[illegible]	-0.45485	0.45103	0.50221
16	0.00308	0.2076[illegible]	0.13653	0.71900	0.10039
17	0.17583	0.00045	0.95824	0.05017	-0.03614
18	-0.29480	0.70535	0.10677	0.02879	-0.44186
19	0.15745	0.96017	-0.04099	-0.04292	0.13546
20	-0.18632	0.67991	0.15782	0.29908	0.10862
21	0.73835	-0.05143	-0.51782	0.17360	0.28807
22	0.69576	-[illegible]541	0.30692	-0.40023	0.41984
23	0.18870	[illegible]47	-0.00282	-0.73899	-0.32374
24	0.00751	0.[illegible]1122	0.05719	0.18376	-0.17748
25	0.53627	0.03781	-0.45485	0.45103	0.50221
26	-0.21109	0.82330	-0.09492	-0.08016	0.24980
27	0.06265	0.24704	-0.23642	-0.13181	0.80005
28	-0.21109	0.82330	-0.09492	-0.08016	0.24980
29	-0.16934	0.76438	0.01779	0.13642	-0.14909
30	-0.03014	0.89811	-0.06778	-0.06215	0.15561
31	-0.01198	0.67959	0.04699	0.05096	0.39501
32	-0.21109	0.82330	-0.09492	-0.08016	0.24980
33	0.15745	0.96017	-0.04099	-0.04292	0.13546
34	0.58008	-0.38759	0.05478	-0.04436	-0.28840
35	0.17526	0.82084	0.08832	0.09266	0.40253
36	0.13557	0.58689	0.07073	0.62997	0.04159
37	0.60238	0.27654	0.37362	0.51262	0.28271
38	0.68257	0.09485	0.37694	0.48031	-0.17557
39	0.76916	0.31036	0.14050	0.11135	-0.14859
40	0.90107	-0.27648	0.04803	0.10817	0.29741
41	0.59298	-0.06228	0.44871	0.36341	-0.43472
42	0.24761	0.14309	0.71094	0.40813	-0.20856

Table II. 3 (Cont.)

Loading of Each Task on Each Factor--Mechanized Infantry

43	0.83983	0.19799	0.29279	0.28194	0.11177
44	0.86582	0.39591	0.18043	0.16315	-0.12599
45	0.67494	-0.35998	0.09390	0.07335	-0.48459
46	0.82636	-0.44157	-0.12200	-0.00888	0.03897
47	0.83983	0.19799	0.29279	0.28194	0.11177
48	0.08201	0.71149	0.18715	-0.04335	0.12181
49	0.90107	-0.27648	0.04803	0.10817	0.29741
50	0.30391	0.25557	0.31728	0.57869	-0.24232
51	0.00751	0.91122	0.05719	0.18376	-0.17748
52	0.17583	0.00045	0.95824	0.05017	-0.03614
53	0.35756	-0.32754	-0.35513	0.71377	-0.14574
54	0.86582	0.39591	0.18043	0.16315	-0.12599
55	0.17583	0.00045	0.95824	0.05017	-0.03614
56	0.69120	-0.19793	0.13660	0.35024	0.47900
57	0.45369	0.35665	0.34603	0.59337	-0.23142
58	0.56791	-0.31106	0.23660	0.57929	0.19583
59	0.58134	-0.17246	0.42807	-0.19713	0.12566
60	0.49850	0.57082	-0.01372	0.43247	0.03511
61	0.70837	-0.56426	0.22142	0.20608	-0.26146
62	0.17583	0.00045	0.95824	0.05017	-0.03614
63	0.83983	0.19799	0.29279	0.28194	0.11177
64	0.77287	-0.38294	0.13998	0.31734	0.01231
65	0.17583	0.00045	0.95824	0.05017	-0.03614
66	0.41561	-0.08238	-0.39131	0.75238	0.19935
67	0.53096	-0.38663	0.56275	-0.36372	-0.18428
68	0.83983	0.19799	0.29279	0.28194	0.11177
69	0.89450	-0.09680	-0.06899	-0.01452	0.06861
70	0.53096	-0.38663	0.56275	-0.36372	-0.18428
71	0.62816	0.14510	0.46430	-0.11286	-0.11477
72	0.90107	-0.27648	0.04803	0.10817	0.29741
73	0.86582	0.39591	0.18043	0.16315	-0.12599
74	0.77287	-0.38294	0.13998	0.31734	0.01231
75	0.17583	0.00045	0.95824	0.05017	-0.03614
76	0.74499	-0.13338	0.14596	0.38421	-0.12139

III. Coordination and Information Processing

(6) Coordinate firing with other vehicles and dismounted elements

(8) Communicate with PL

(17) Report vehicle readiness to SL

(42) Make new range cards as needed

(52) Check on support fire availability

(62) Communicate with company and/or artillery as needed

(75) Call indirect fire required for disengagement

IV. Preservation of Forces and Regrouping Activity

(14) Cover disengaging squads

(16) Fire to protect regrouping

(23) Mark routes between possible locations

(50) Conduct reconnaissance

(53) Decide to engage unexpected fire or not

(57) Select positions for cover, concealment observation, and fire

(66) Decide when (or if) to relocate

V. Orientation to Friendly and Enemy Forces

(7) Maintain knowledge of squad's location

(15) Maintain concealed disengagement

(27) Fire at areas

Tank Crew (Armor) Solution

For tank crew tasks, the five factor solution cumulatively accounted for 77.9% of the unrotated variance. The final rotated factor loading of each task on each factor is presented in Table II.4. The factor names selected were: Decision Making and Planning. Coordination and Information Processing, Preparation and Operation of Weapons, Command and Control Activity, and Target Designation and Tracking. A sample of the tasks loading on each factor is presented below in support of the factor names selected.

Table II.4

Loading of Each Task on Each Factor--Armor

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
01	0.37500	0.66384	-0.40753	0.14787	-0.35372
02	0.37500	0.66384	-0.40753	0.14787	-0.35372
03	0.90142	0.11523	0.21744	0.04130	0.08915
04	0.90142	0.11523	0.21744	0.04130	0.08915
05	0.90142	0.11523	0.21744	0.04130	0.08915
06	0.90142	0.11523	0.21744	0.04130	0.08915
07	0.90142	0.11523	0.21744	0.04130	0.08915
08	0.15847	0.83749	-0.31106	0.13396	-0.18229
09	-0.25589	0.67552	-0.15274	0.25865	-0.15429
10	0.49307	0.48055	-0.16797	0.59072	-0.17655
11	0.70507	-0.24320	0.20646	0.22753	0.09911
12	0.81864	0.39369	-0.02224	-0.00270	-0.06819
13	0.81864	0.39369	-0.02224	-0.00270	-0.06819
14	0.04822	-0.05532	0.10762	0.77157	-0.09924
15	0.28619	-0.18801	-0.00053	0.44861	0.78591
16	0.81658	-0.23544	-0.21513	0.30938	0.27265
17	0.57319	0.20327	-0.14201	0.58030	0.22948
18	0.49677	0.34467	-0.30832	0.68296	0.09439
19	0.25472	-0.01833	0.17434	-0.10265	0.80847
20	0.07189	-0.08032	0.55217	0.02114	0.25780
21	-0.33830	-0.45089	0.51181	-0.45007	0.36072
22	0.81658	-0.23544	-0.21513	0.30938	0.27265
23	0.18099	0.46266	-0.01207	0.72370	0.32582
24	0.65400	0.22897	-0.32506	0.49453	0.17062
25	0.25589	0.27880	0.12892	0.77458	-0.36517
26	0.58797	0.34947	-0.01561	0.51504	-0.03308
27	0.23673	0.83690	0.22261	0.36277	0.07156
28	0.23673	0.83690	0.22261	0.36277	0.07156
29	0.72294	0.32515	0.36769	0.02529	0.31646
30	0.72115	0.10818	-0.15543	0.36493	-0.01095
31	0.23788	-0.02586	0.37800	0.65661	-0.09629
32	0.34757	0.76364	-0.35276	-0.02981	-0.10651
33	0.61252	0.05387	0.21495	0.36380	0.27836
34	0.45952	0.59636	-0.11285	0.16710	0.34926
35	0.57711	0.15781	-0.30673	0.39159	0.16495
36	0.12640	-0.05593	0.17339	-0.27297	0.81769
37	0.07746	0.68822	0.35481	0.48265	-0.19416
38	-0.17903	-0.27938	0.39515	-0.54989	0.61444
39	0.66937	-0.41441	-0.10027	0.41671	0.01927
40	-0.05784	0.61856	0.02811	0.43932	0.52971
41	0.06085	0.73711	-0.44893	-0.02060	0.09780
42	0.36216	0.05774	0.12947	0.11905	0.87758

Table II. 4 (Cont.)

Loading of Each Task on Each Factor--Armor

43	0.20761	0.01094	0.12761	-0.08066	0.85700
44	0.30868	0.48588	0.03996	0.06680	-0.39831
45	-0.13758	-0.17360	0.49218	-0.38241	0.27604
46	-0.13758	-0.17360	0.49218	-0.38241	0.27604
47	0.07631	-0.10110	0.83864	0.09963	0.11972
48	0.07631	-0.10110	0.83864	0.09963	0.11972
49	0.07631	-0.10110	0.83864	0.09963	0.11972
50	0.50934	-0.23473	0.61879	-0.11867	-0.28306
51	0.42981	-0.58096	0.35403	0.25533	-0.01191
52	0.53595	0.21516	-0.09335	0.07713	-0.55640
53	0.47924	0.05441	0.32153	-0.18165	-0.05519
54	0.40720	-0.00087	0.79329	0.07231	-0.13191
55	0.61693	0.13090	0.60388	0.17626	0.00001
56	-0.14416	0.19377	0.26294	0.73031	0.02022
57	0.39750	-0.59415	0.33267	0.32616	-0.03660
58	0.07631	-0.10110	0.83864	0.09963	0.11972

I. Decision Making and Planning

(3) Select firing position for tanks

(4) Select observation posts

(5) Select routes

(10) Supervise defensive preparations

(11) Inspect for readiness

(16) Determine when to commence engagement

(22) Decide when (or if) to relocate

(26) Issue spot reports

(30) Plan fire control measures

(52) Conduct communication operation checks

(53) Set head space and timing on 50 CAL MG

II. Coordination and Information Processing

(2) Coordinate with ARTY FO (Fire Planning)

(8) Communicate positioning of tanks to the tank CDRS

(9) Operate intercom/radio

(27), (28) } Coordinate with gunner/driver

(32) Report enemy sightings

(37) Issue crew fire commands

(40) Control driver actions when moving

III. Preparation and Operation of Weapons

(21) Fire 50 CAL MG

(45) Fire main gun

(46) Fire COAX MG

(47) Load COAX MG

(48) Load 50 CAL MG

(50) Load selected rounds

(54) Operate breach mechanism

(58) Unload nonoperational main gun rounds

IV. Command and Control Activity

(14) Prepare PLT fire plan

(18) Control employment of coordinated PLT tank fire

(23) Control formations on the move

(25) Issue fragmentary orders

(31) Escor. PL or TM CDR during inspection

(56) Advise gunner when COAX and main gun can fire

V. Target Designation and Tracking

(15) Acquire targets

(19) Operate laser range finder

(43) Track targets

Fire Support Team (FIST) Solution

For the FIST, the five factor solution cumulatively accounted for 89.9% of the unrotated variance. The final rotated factor loadings are presented as Table II.5. The factors were named: Fire Control, Fire Planning and Allocation, Orientation to Friendly and Enemy Troops, Information Relay and Processing, and Target Data Acquisition. A sample of the tasks loading on each factor is presented below in support of the factor names selected.

I. Fire Control

(10) Adjust corrective fire

(11) Engage targets of opportunity

(13) Determine when to request end of mission

(14), (15), (16), (20), (22), (23) Adjust ICM, counterfire, suppression, TACAIR, helicopters, Naval guns, etc.

(32) Coordinate with FIST chief

(34) Coordinate with FDC

(39) Acquire targets

(54) Adjust multiple missions

(55) Report target engagement results

Table II.5

Loading of Each Task on Each Factor--FIST

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
01	0.27810	0.66096	0.09644	0.47290	0.16179
02	0.24158	0.91496	0.17951	0.19767	-0.09824
03	0.24158	0.91496	0.17951	0.19767	-0.09824
04	0.24158	0.91496	0.17951	0.19767	-0.09824
05	0.28136	0.27247	0.90482	0.02240	0.15214
06	0.26722	0.62168	0.49017	0.09019	0.00468
07	-0.02029	-0.14454	0.32349	0.01500	0.79146
08	0.19538	0.15167	0.81585	0.19913	0.22181
09	0.19538	0.15167	0.81585	0.19913	0.22181
10	0.89013	0.20320	0.28848	0.25045	0.03547
11	0.89013	0.20320	0.28848	0.25045	0.03547
12	0.46554	-0.00472	0.79331	0.18510	0.01285
13	0.66032	-0.21292	0.55321	-0.07370	-0.30403
14	0.92966	0.10663	0.06400	-0.03796	0.16248
15	0.92966	0.10663	0.06400	-0.03796	0.16248
16	0.92966	0.10663	0.06400	-0.03796	0.16248
17	0.23984	0.54542	0.52739	0.39075	-0.07016
18	0.45390	0.82339	0.03659	0.08678	-0.03393
19	0.22459	0.81681	0.08623	0.05543	-0.48240
20	0.81891	0.43943	0.16873	0.13637	-0.01208
21	0.89013	0.20320	0.28848	0.25045	0.03547
22	0.81891	0.43943	0.16873	0.13637	-0.01208
23	0.81891	0.43943	0.16873	0.13637	-0.01208
24	0.59321	0.68975	0.23973	-0.03233	0.12191
25	0.81891	0.43943	0.16873	0.13637	-0.01208
26	0.81891	0.43943	0.16873	0.13637	-0.01208
27	0.79500	0.12481	0.07105	0.37804	0.23969
28	0.72136	0.13207	-0.26949	0.24024	0.06282
29	0.04962	0.30050	0.08727	0.75351	-0.27011
30	0.06841	0.39515	0.19245	0.81902	0.23875
31	0.27768	0.06265	0.08837	0.92201	0.06802
32	0.81891	0.43943	0.16873	0.13637	-0.01208
33	0.81891	0.43943	0.16873	0.13637	-0.01208
34	0.81891	0.43943	0.16873	0.13637	-0.01208
35	0.36762	0.18564	0.71717	-0.29640	0.30619
36	-0.01681	-0.20508	0.31447	0.16864	0.59746
37	0.28136	0.27247	0.90482	0.02240	0.15214
38	0.28136	0.27247	0.90482	0.02240	0.15214
39	0.62416	-0.43665	0.08435	0.08397	0.52153
40	0.51292	-0.00198	0.31875	-0.27247	0.60984
41	0.30224	0.11202	0.52816	-0.16292	0.59400
42	0.89013	0.20320	0.28848	0.25045	0.03547
43	0.59321	0.68975	0.23973	-0.03233	0.12191

Table II.5 (Cont.)

Loading of Each Task on Each Factor--FIST

44	0.80792	-0.19363	0.16716	-0.12906	-0.23148
45	0.89013	0.20320	0.28848	0.25045	0.03547
46	0.89013	0.20320	0.28848	0.25045	0.03547
47	0.89013	0.20320	0.28848	0.25045	0.03547
48	0.89013	0.20320	0.28848	0.25045	0.03547
49	0.89013	0.20320	0.28848	0.25045	0.03547
50	0.89013	0.20320	0.28848	0.25045	0.03547
51	0.89013	0.20320	0.28848	0.25045	0.03547
52	0.68281	0.46163	0.35925	0.08533	0.16597
53	0.89013	0.20320	0.28848	0.25045	0.03547
54	0.89013	0.20320	0.28848	0.25045	0.03547
55	0.89013	0.20320	0.28848	0.25045	0.03547
56	0.38246	0.25340	-0.12345	0.80728	0.07895
57	0.27768	0.06265	0.08837	0.92201	0.06802
58	0.27768	0.06265	0.06837	0.92201	0.06802
59	0.28074	-0.07151	-0.02058	0.84067	-0.39310

II. Fire Planning and Allocation

(1) Receive orders and plans from TM-CDR

(3) Coordinate with PI's

(4) Coordinate with FSO

(6) Plan WPN SYS, round, FUZE, etc., for each target

(17) Approve FO calls for fire

(18) Redirect FO calls for fire

III. Orientation to Friendly and Enemy Troops

(5) Select observation posts

(8) Orient for direction

(9) Determine exact position on the ground

(12) Adjust CLGP (laser)

IV. Information Relay and Processing

(29) Relay calls for fire

(31) Receive plans and orders from PL

(57) Receive plans and orders from FIST chief

(59) Operate field telephone

V. Target Data Acquisition

(7) Operate laser locator-designator

(40) Determine range of target

(41) Determine direction of target

Artillery Solution

For the artillery, the five factor solution cumulatively accounted for 83.1% of the unrotated variance. The final rotated loading of each task on each factor is presented as Table II.6. The factors were named: Orientation and Preparation, Command and Fire Control, Quality Assurance, Communication and Ammunition Logistics, and Safety and Precautionary Measures. A sample of the task loading on each factor is presented below in support of the factor names selected.

Table II. 6

Loading of Each Task on Each Factor--Artillery

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
01	-0.02327	0.69952	0.43832	-0.31440	0.32615
02	0.13392	0.78870	-0.18273	-0.44552	0.00486
03	0.43975	0.59952	0.19056	-0.10287	0.24682
04	-0.02327	0.69952	0.43832	-0.31440	0.32615
05	-0.21748	0.31392	0.76329	0.04523	0.00731
06	-0.15999	0.73385	0.02159	-0.40115	-0.17227
07	0.13921	0.03669	0.35553	0.21748	0.81533
08	0.17817	0.15980	0.76953	0.18954	0.09100
09	0.59553	0.56120	0.21385	-0.05302	0.22291
10	0.13456	0.33751	0.04438	-0.09347	0.73184
11	0.61049	0.19050	0.04303	0.00377	0.67166
12	-0.13214	0.55105	0.12861	0.27647	0.61731
13	0.44162	0.77233	0.13400	-0.00560	0.23160
14	-0.43120	0.72929	-0.25075	0.04193	-0.17794
15	0.44162	0.77233	0.13400	-0.00560	0.23160
16	0.64945	0.31361	0.45703	-0.02417	-0.05267
17	-0.02327	0.69952	0.43832	-0.31440	0.32615
18	0.95695	0.02827	0.07120	0.22739	0.07004
19	0.95695	0.02827	0.07120	0.22739	-0.07004
20	0.95695	0.02827	0.07120	0.22739	0.07004
21	0.95695	0.02827	0.07120	0.22739	0.07004
22	0.91476	0.11613	0.20752	-0.04470	0.17515
23	0.91476	0.11613	0.20752	-0.04470	0.17515
24	0.77133	-0.00526	-0.07280	0.05997	0.45824
25	0.95695	0.02827	0.07120	0.22739	0.07004
26	0.95695	0.02827	0.07120	0.22739	0.07004
27	0.95695	0.02827	0.07120	0.22739	0.07004
28	0.95695	0.02827	0.07120	0.22739	0.07004
29	0.83636	0.01278	0.14947	0.31355	-0.28710
30	0.95695	0.02827	0.07120	0.22739	0.07004
31	0.55629	0.24126	0.45310	-0.12804	0.48764
32	0.18437	0.00250	0.83205	-0.02110	0.42619
33	0.35950	0.04686	0.73691	0.00980	0.27050
34	0.70274	0.26719	0.08950	-0.45941	0.18350
35	0.24846	-0.13077	-0.04925	0.69237	0.43637
36	0.44164	-0.15336	0.18245	0.47860	0.02696
37	0.46928	-0.23257	-0.00230	0.73790	-0.09772
38	0.59305	-0.19267	-0.08253	0.58511	0.29526
39	0.08833	-0.16414	0.03450	0.85648	0.05829
40	0.10748	0.55409	0.24592	-0.07797	-0.48121
41	0.47169	-0.18479	0.20027	0.67885	-0.34531
42	0.21108	0.03224	0.90363	0.10186	-0.12509
43	0.21108	0.03224	0.90363	0.10187	-0.12509
44	0.62829	-0.08131	0.29194	0.55984	-0.35992
45	0.62829	-0.08131	0.29194	0.55984	-0.35992
46	0.08833	-0.16414	0.03450	0.85648	0.05829
47	0.80657	0.10610	0.30167	0.03470	-0.19694
48	0.32456	0.10205	0.19039	0.32132	0.13850

I. Orientation and Preparation

(9) Lay the weapon

(16) Determine piece to crest range

(20) Lay cannon on initial direction of fire with distant aiming point

(23) Verify direction of fire with reciprocal check as adjacent piece

(26) Boresight the panoramic telescope with a distant aiming point

(30) Refer the piece

(31) Orient a map with a compass

(34) Locate a point on a map using the grid reference system

(38) Emplace/recover aiming posts

II. Command and Fire Control

(1) Supervise battery when it occupies a firing position

(4) Control fire of the battery

(6) Insure ammunition is distributed IAW anticipated needs of FDC

(13) Order azimuths marked

(14) Order the prefire checks performed

(15) Measure and report site to the crest

(17) Supervise section during firing

III. Quality Assurance

(5) Insure sections store, segregate, and protect ammunition

(8) Insure weapon is ready for action

(33) Determine present location by terrain association

(42) Recognize ammo types by color coding

(43) Identify fuzes and fuze wrenches by type

IV. Communication and Ammunition Logistics

(35) Lay communication wire to FDC

(36) Connect wire to telepost terminal on vehicle

(39) Store ammunition at a cannon position

(41) Prepare ammunition for firing

(46) Prepare propellant charge

V. Safety and Precautionary Measures

(7) Insure weapon is properly emplaced

(10) Select aiming points for gunner

(11) Sight to the crest

(12) Order when to boresight

Consolidation of Factors

The 20 factors (4 solutions x 5 factors) were examined for logical commonality. Five factor groups seemed to be involved and two factors (Decision Making and Planning, Quality Assurance) remained somewhat independent. The grouping is shown in Table II. 7 along with the generic name assigned to each group. Decision Making and Planning was subsequently included in Command and Control. The five generic groups are the five factors included and assessed in the PERFECT model.

Table II.7

Consolidation of Factors

Factors	Unit Type				
	Mechanized Infantry	Armor	FIST	Artillery	Generic Name
	Command and Control	Command and Control	Fire Control	Command and Fire Control	Command and Control
	Combat Activity	Preparation and Operations of Weapons	Fire Planning and Allocation		Combat Activity
	Coordination and Information Processing	Coordination and Information Processing	Information Relay and Processing	Communication and Ammunition Logistics	Coordination and Information Processing
	Force Preservation and Regrouping Activity	Target Designation and Tracking	Target Data Acquisition	Safety and Precautionary Measures	Force Preservation and Regrouping Activity
	Orientation to Friendly and Enemy Troops		Orientation to Friendly and Enemy Troops	Orientation and Preparation	Orientation to Friendly and Enemy Troops
		Decision Making and Planning			
				Quality Assurance	

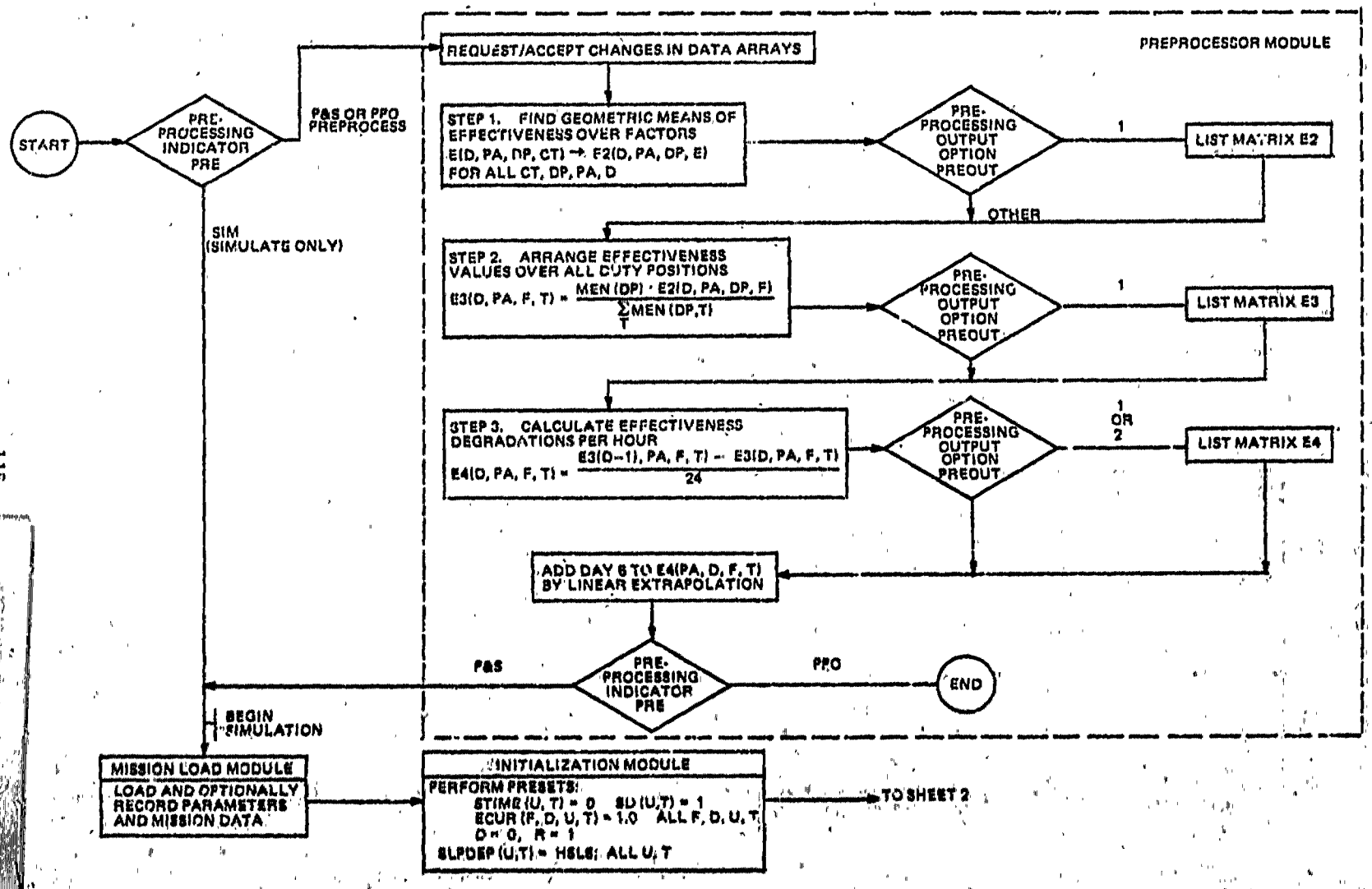
APPENDIX III

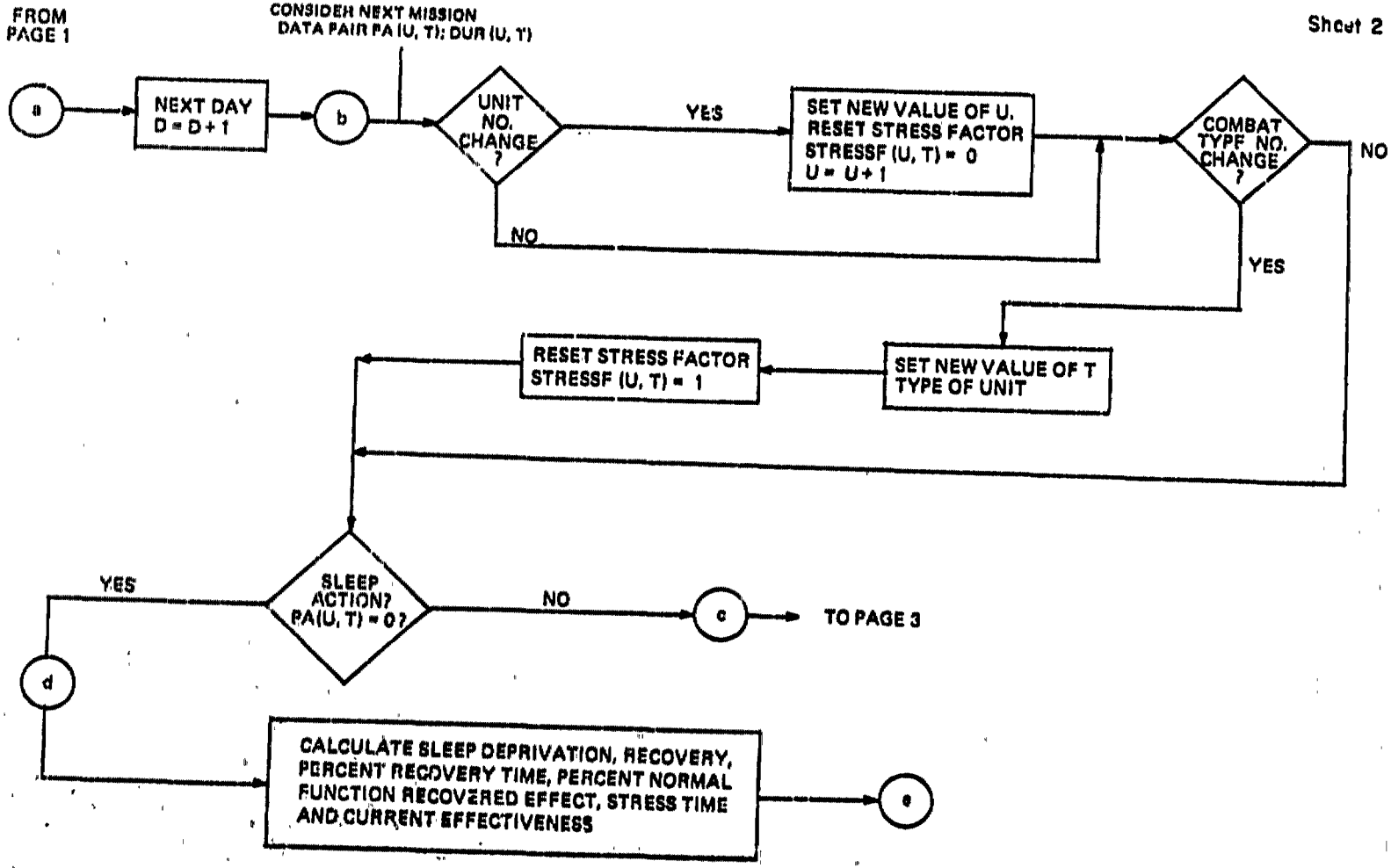
DETAILED MODEL FLOW CHART

Note: In this model flow chart, the following variable names have been simplified for each of presentation:

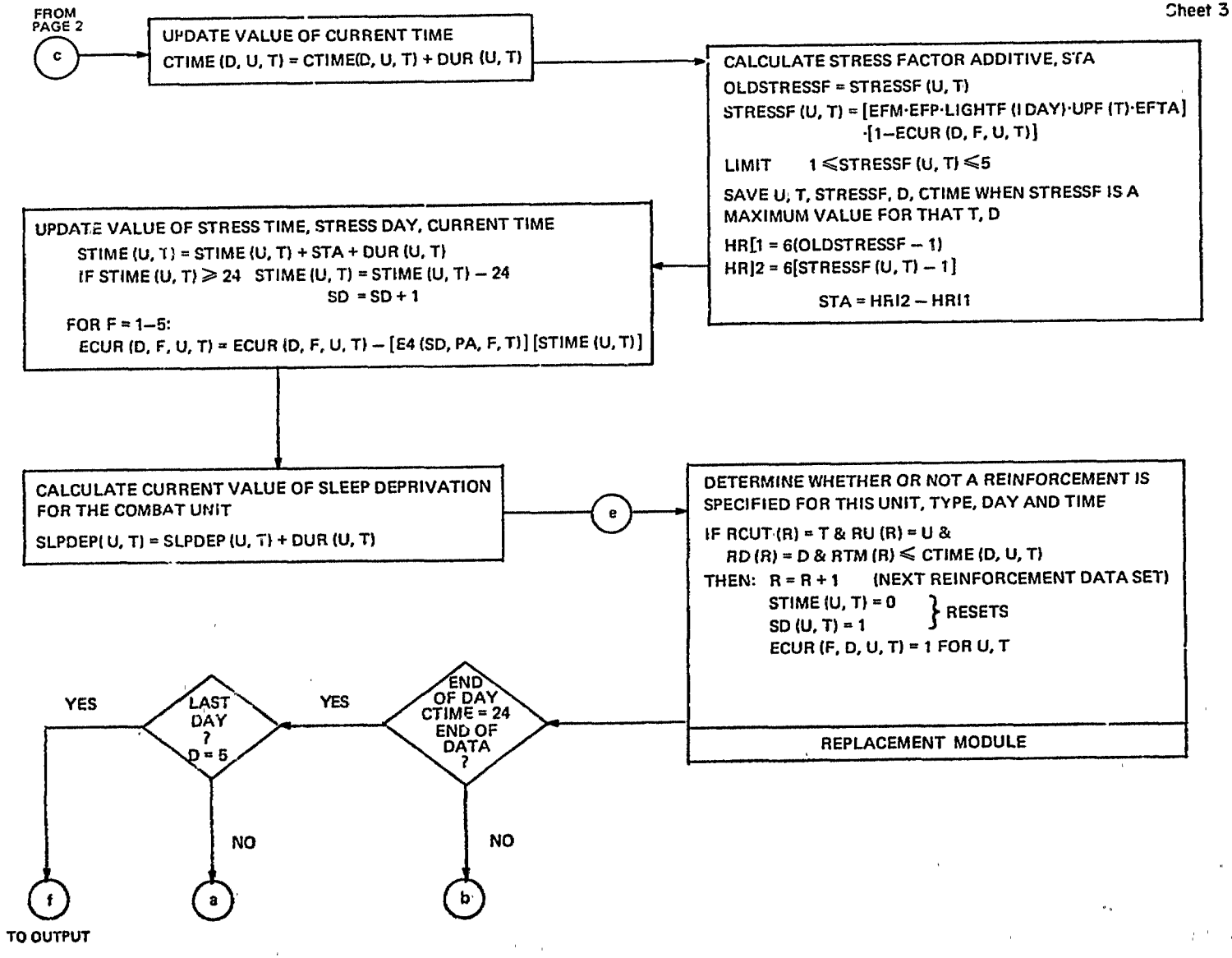
Meaning	Variable Name Used	Actual Fortran Name
Factor	F	FAC
Effectiveness	E	EFF
Day	D	IDAY
Duty Position	DP	IDP
Critical Task	CT	ICT
Unit Type	T	ITYPE
Unit Number	U	IUNNO

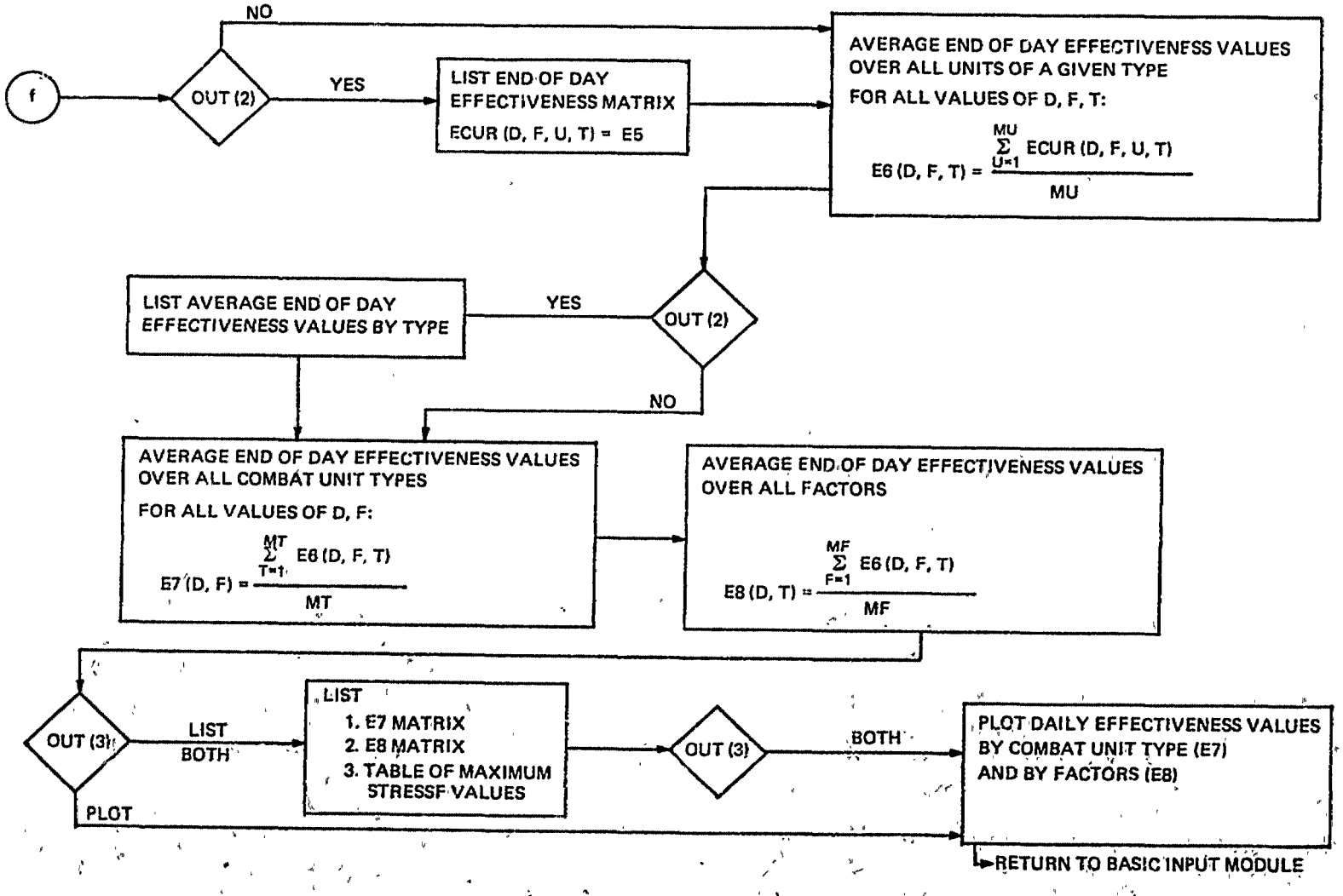
'PERFECT' MODEL FLOW CHART




FROM PAGE 1
a
NEXT DAY
D = D + 1
b
CONSIDER NEXT MISSION
DATA PAIR PA (U, T); DUR (U, T)
UNIT NO. CHANGE ?
YES
SET NEW VALUE OF U.
RESET STRESS FACTOR
STRESSF (U, T) = 0
U = U + 1
NO
COMBAT TYPE NO. CHANGE ?
NO
YES
SET NEW VALUE OF T
TYPE OF UNIT
RESET STRESS FACTOR
STRESSF (U, T) = 1
SLEEP ACTION?
PA(U, T) = 0 ?
YES
NO
c
TO PAGE 3
d
CALCULATE SLEEP DEPRIVATION, RECOVERY, PERCENT RECOVERY TIME, PERCENT NORMAL FUNCTION RECOVERED EFFECT, STRESS TIME AND CURRENT EFFECTIVENESS
e

Sheet 2


FROM PAGE 2
c
UPDATE VALUE OF CURRENT TIME
CTIME (D, U, T) = CTIME(D, U, T) + DUR (U, T)
CALCULATE STRESS FACTOR ADDITIVE, STA
OLDSTRESSF = STRESSF (U, T)
STRESSF (U, T) = [EFM·EFP·LIGHTF (I DAY)·UPF (T)·EFTA]
·[1–ECUR (D, F, U, T)]
LIMIT 1 ⩽ STRESSF (U, T) ⩽ 5
SAVE U, T, STRESSF, D, CTIME WHEN STRESSF IS A MAXIMUM VALUE FOR THAT T, D
HR]1 = 6(OLDSTRESSF – 1)
HR]2 = 6[STRESSF (U, T) – 1]
STA = HRI2 – HRI1
UPDATE VALUE OF STRESS TIME, STRESS DAY, CURRENT TIME
STIME (U, T) = STIME (U, T) + STA + DUR (U, T)
IF STIME (U, T) ⩾ 24 STIME (U, T) = STIME (U, T) – 24
SD = SD + 1
FOR F = 1–5:
ECUR (D, F, U, T) = ECUR (D, F, U, T) – [E4 (SD, PA, F, T)] [STIME (U, T)]
CALCULATE CURRENT VALUE OF SLEEP DEPRIVATION FOR THE COMBAT UNIT
SLPDEP(U, T) = SLPDEP (U, T) + DUR (U, T)
e
DETERMINE WHETHER OR NOT A REINFORCEMENT IS SPECIFIED FOR THIS UNIT, TYPE, DAY AND TIME
IF RCUT (R) = T & RU (R) = U &
RD (R) = D & RTM (R) ⩽ CTIME (D, U, T)
THEN: R = R + 1 (NEXT REINFORCEMENT DATA SET)
STIME (U, T) = 0
SD (U, T) = 1
} RESETS
ECUR (F, D, U, T) = 1 FOR U, T
REPLACEMENT MODULE
END OF DAY CTIME = 24 END OF DATA ?
YES
LAST DAY ? D = 5
YES
NO
NO
f
TO OUTPUT
a
b


f
OUT (2)
NO
YES
LIST END OF DAY EFFECTIVENESS MATRIX
ECUR (D, F, U, T) = E5
AVERAGE END OF DAY EFFECTIVENESS VALUES OVER ALL UNITS OF A GIVEN TYPE
FOR ALL VALUES OF D, F, T:
E6 (D, F, T) = Σ (U=1 to MU) ECUR (D, F, U, T) / MU
LIST AVERAGE END OF DAY EFFECTIVENESS VALUES BY TYPE
YES
OUT (2)
NO
AVERAGE END OF DAY EFFECTIVENESS VALUES OVER ALL COMBAT UNIT TYPES
FOR ALL VALUES OF D, F:
E7 (D, F) = Σ (T=1 to MT) E6 (D, F, T) / MT
AVERAGE END OF DAY EFFECTIVENESS VALUES OVER ALL FACTORS
E8 (D, T) = Σ (F=1 to MF) E6 (D, F, T) / MF
OUT (3)
LIST
BOTH
PLOT
LIST
1. E7 MATRIX
2. E8 MATRIX
3. TABLE OF MAXIMUM STRESSF VALUES
OUT (3)
BOTH
PLOT DAILY EFFECTIVENESS VALUES BY COMBAT UNIT TYPE (E7) AND BY FACTORS (E8)
RETURN TO BASIC INPUT MODULE